STUDIES ON TOPOGRAPHICAL AND HYDROMORPHOLOGICAL RELATIONSHIPS

(For River Basins In A Region of North India)

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KANAKENDRA NATH PAL

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TO

MY MOTHER

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CERTIFICATE

This is to certify that the thesis entitled " Studies on Topographical and Hydromorphological Relationships for River Basins in a Region of North India" by Kanakendra Nath Pal is a record of work carried out under my supervision and has not been submitted elsewhere for a degree.

DR. S. RAMASESHAN
ASSOCIATE PROFESSOR
DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
KANPUR

ABSTRACT

The topographical and hydromorphological relationships were estimated for a region in North India. The streamflow observations were available only for a small number of streams. By correlating hydrologic characteristics with physiographic characteristics, it is possible to estimate the hydrologic characteristics of ungaged watersheds in the region. Since all estimations were carried out by using regression analysis it will also indicate the confidence intervals for any hydrologic estimate derived from regression relationships, thus indicating the reliability of empirical estimations.

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LIST OF SYMBOLS

A = Constant Intercept in regression equation .

A_1, A_2, A_3 and A_4

= All constant intercepts in regression equation for subregions 1, 2, 3, and 4 respectively .

A_d = Catchment area of drainage basin,

B = Exponential Constant in regression equation (eq.17) .

B_1 , B_2, B_3 and B_4

= All multiplication constants in regression equations for subregions 1, 2, 3 and respectively.

C = Multiplication constant in equation (eq. 24).

L = Length of stream,

$\bar{L}u$ = Mean length of segment of order u,

n = Exponential constant in equation (eq.24).

p = Multiplication constant in equation (eq. 44).

Q = Average annual monsoon runoff,

Qm = Average annual peak flood,

q = Exponential constant in equation (eq.44) .

R = Multiplication constant in equation (eq. 36).

R_L = Length ratio.

r = Correlation coefficient.

S = Exponential constant in equation (eq.36).

S_* = Standard error of estimate for *.

Se, Sx, Sy and Sy/x

= All standard errors of estimate for e,x,y and y/x respectively.

X	=	The independent random variable.
Y	=	The dependent random variable .
A	=	Population value for intercept.
β	=	Population value for slope.
Δ	=	Increament or decreament.
ϵ	=	Error in regression equation
Σ	=	Summation over points.
σ_ϵ	=	Standard error of estimate for ϵ .

LIST OF TABLES.

CHAPTER 1

INTRODUCTION

1.1 GENERAL

1.1.1 Hydrologic Characteristics of Basins: Some of the important hydrologic factors characterising river basins are runoff, peak discharge, sediment and groundwater. Runoff is that part of precipitation which appears in surface streams in either perennial or intermittant form. According to Chow (1)* runoff of a watershed may be classified as surface runoff, subsurface runoff and groundwater runoff. Surface runoff is a part of total runoff which travels over the ground surface or through a channel to reach the basin outlet immediately after the rain. Subsurface runoff is also a part of the precipitation; but which infiltrates through the soil mass and moves laterally above the main groundwater toward the streams. Groundwater runoff occurs due to deeper percolation of infiltrated water which has passed into the groundwater and which subsequently discharges into the stream .

Generally two aspects of streamflow (10, 17,18) are important in hydrologic design and they are respectively: a. total runoff and b. peak runoff. Streamflow hydrographs (1, 9) are useful for estimating the total amount of water available and its variability; and to determine when irrigation, power and other demands are to be met; whether diversion alone is satisfactory or whether storage is also required, and, when storage is required, the storage to be provided to meet the demands. The second aspect is of floods where, if data are available for a long time period, one may use (1, 21,26)

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* Numbers refer to entries in the List of References

statistical methods and frequency analysis of flood peaks or else use physical concept and unit hydrograph or other similar procedures.

Sediment (1, 18) is defined as the amount of loose soil particles or debris, found on the bottom or sides of a river, channel etc. which has a capacity to move along with the running water to an ocean, a river or a channel. Gravity provides the force by which both excess water and movable debris are brought from higher to lower elevation. The important factor in considering sediment in a hydrological design scheme is to protect the dams and barrages from erosion and deposition. The following problem usually arises with respect to the sediment: Given a drainage area and a cross-section of its stream channel, how can the rate of sediment load passing through this cross-section, be predicted and described as a function of hydrometeorological and physiographic characteristics of the basins? Groundwater (1, 9) is water beneath the soil surface where voids in the soil mass are saturated with water at or above atmospheric pressure. Excess water causes high percolation rate and subsequently passes into the ocean or stream. This study does not deal with sediments or groundwater.

1.1.2 Streamflow Data: In order that hydrologic design can be done well, it is necessary to have reliable data of sufficiently long length. For stream flow the general practice is to observe the stream gauge data and using appropiate rating curves, estimate the corresponding discharge data. The stage data can be observed at discrete intervals of time, say, once a day or so, or else recorded automatically by a self recording stream gauge. The discharge data obtained from stage data can then

be used for various hydrologic analyses ; for example, the streamflow data can be analysed directly to estimate the statistical variations and parameters ; these may be used to estimate the availability and variability of surface runoff by using mass curve analysis, sequent peak alogrithm etc. The volume of storage necessary to meet any particular demand may also be estimated. A correlation between rainfall and runoff may be established by hydrologic simulation models, by unit hydrograph procedures etc.; and from the observed peak discharges, a frequency analysis of flood peaks may be performed for estimating the design flood.

1.1.3 Hydrologic Analysis With Limited or No Data : It is possible that streamflow data are not available for basins under consideration and if they are available the data are not of sufficient length. In such cases it becomes imperative to estimate runoff data by empirical procedures(2, 9).

The runoff data may be considered to be a purely random variable and in case the parameters are known, it is possible to define the confidence interval for specified levels of probability. It may however be noted, as indicated by Chow (2), that runoff from a drainage basin is a product of a hydrologic cycle influenced by two major groups of factors, namely, climatic factors and physiographic factors. Climatic factors include mainly the effect of rain, snow and evapotranspiration all of which exhibit seasonal changes in accordance with the climatic environment. Physiographic factors may be further

classified into two kinds; basin characteristics and channel characteristics. Basin characteristics includes such factors as size, shape and slope of drainage area, permeability and capacity of groundwater reserviors,presence of lakes and swamps, land use etc. Channel characteristics are related mostly to hydraulic properties of the channel which govern the movement and configuration of flood waves and develop the storage capacity.

Empirical correlation between climatic and physiographic factors, on the one hand, and streamflow data, on the other hand, has been used for quite a long time by hydrologists . A brief description of some of the empirical procedures are indicated below.

i) Daily, seasonal, and annual runoff have been correlated with respective rainfalls, as in the case of Strange's table, Barlow's curves, etc. (9).

ii) The runoff from or total runoff from a basin is estimated from climatic factors, for example Khosla's formula (2, 9) as follows;

$$R=P-\frac{T-32}{9.5} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad 1$$

where R is the annual runoff in inches; T is the mean temp. in degree Fahrenheit, and P is the annual rainfall in inches.

iii) The runoff data or groundwater recharge are related to the climatic factors by co-axial correlation relationship (1, 9).

iv) The peak runoff for a basin is estimated in terms of the area by the Ryve's formula, Dicken's formula etc. (2, 9). For example Ryve's formula is given as

$$Q=CA^{2/3} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \quad 2$$

in which, C= local co-efficient depending on the rainfall, soil and slope

of the area; and A=Catchment area.

Dicken's formula is given as

$$Q = C\,A^{0.75} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 3$$

in which C and A are as defined above.

v) More complicated empirical relationship between the peak flow of a given frequency and hydrometeorological factors have also been established, for example, Murray (19) recommends the following formula

$$Q = C' \, A^{2/3} S^{1/4} \, (C_p/C_l) \, (.6L/L_c)^{1/4} \ldots\ldots\ldots \quad 4$$

where, Q = peak discharge in cusecs.

A = area of catchment in sq. miles

L = length of main (longest) stream in miles from the gauging station to periphery of the catchment.

L_c = length along the main stream in miles from near the centre of gravity of the catchment area to the gauging site.

S = " mean " slope of the main stream in ft./ mile.

'S' is given by the relation $S = \dfrac{N}{\sum 1/\sqrt{S_i}}$, where N = number of equal segments into which the main stream is divided .

S_i = stream slope in each segment in ft./ mile .

(C_p/ C_l) = " peaking capability" factor which depends on " drainage density " (D_d).

(.6L)/ (L_c) = shape factor for an individual catchment.

C' = a constant which depends on (i) rainfall- depth- duration and frequency (ii) the ratio of areal to point rainfall for a given area and (iii) infiltration rate.

Some of the drawbacks of empirical relationships are i) the relationship is to be established for each region. ii) the parameters pertaining to a region are to be estimated from data available for that region, and , iii) the relationships so established are purely empirical, they are subject to error and hence the error limits are also to be defined whenever possible.

1.1.4 Landforms : The landform at any place is regarded (3,11,13,23) as (i) the formation of soil and effect of climate on soil, and, (ii) the effect of water and climate on soil . The first factor by which landforms occur is due to the processes of disintegration on rocks. The disintegration process is due to climatic variations and natural causes. When precipitation occurs on the disintegrated rock masses they settle down gradually due to the gravitational pull. The second factor is regarded as the result of water on the earth through climate. When rainfall occurs the excess water on the soil mass tends to move laterally from higher elevation to lower elevation . The passages of water movement on the earth on which rain water follows causes rivers, lakes etc.

It is reasonable to assume (3,13) that the pattern of channel itself is formed by flows which apply sufficient force to mould the channel and are also retained within the channel, rather than by those which occupy the entire cross- section of a valley during periods of flood.

In many rivers it has been studied that the bankfull storage recurs once in each year or once in every two years on the average. Additional observations indicate that the cross- section of a straight reach of a channel is adjusted to a range of discharges which provide a shear stress balanced by the resistance of the banks. A meandering channel migrates both across and down its alluvial plain. The stability of the meandering channel is a function of the shear stress on the outer bank and of the associated deposition on the inner or convex bank.

Gullies, a channel worn by water, are tributaries formed or enlarged due to catastropic flood in every climate and physiographic environment. During this catastropic rare flood, major changes in channel direction and form occur regularly, particularly in the semi arid and humid regions. In a semiarid physiographic region the familiar sequence of drought, forest fires, floods, erosion and landslides illustrate the significance of particular combination of climatic events in geomorphic process.

It has been observed in many rills or streams that water flows without any of the water flowing to it over the land surface. It happens due to the fact that all the rainfall apparently infiltrates into the soil and this rain water moves laterally through the soil. Under this circumstance the water does not carry much sediment. Whatever mineral moves down the rills must be excavated from the rills. Another possibility is that the mass movement tends to narrow the rill and water flow keeps the channel in equilibriun with the soil creep. Considering the large amounts

of mineral carried in solution in this climatic region, it is quite possible that the reduction of the rill proceeds primarily by weathering and export of weathering product solution. In limestone terrain the rate of solution is perhaps more easily accepted. Nevertheless in both the cases solution plays a significant role in evolution of features of landscape and individual catastropic events are probably of relatively little importance.

It has been observed that a large river may be divided into a numbers of small streams. According to Horton, as modified by Strahler (24), the smallest streams of a given river basin is called first order stream. When two first order streams meet, a second order stream is formed; when two second order streams join, a stream of third order is formed and so on. Horton, Strahler and others (10,22,23,24) defined various geomorphological parameters of a river basin.

As the soil and landform are moulded by the environment and particularly hydrologic cycle, the hydrologic characteristics of the basin and the geomorphological characteristics of the basin should be closely related. Hence when hydrologic data are scarce it may be possible to establish correlation between available hydrologic and geomorphologic data. From known geomorphological characteristics, estimation of hydrologic characteristics of basin without data can then be done. Correlation with geomorphologic parameters may be more meaningfull than with simple physiographic paramaters like area. The estimation of geomorphologic characteristics requires 1 inch = 1 mile toposheet. They are not available for study. Hence in this study it is proposed

to correlate hydrologic characteristics only with relevant physiographic characteristics for which data are available.

1.2 Objective of the Study :

The objective of the study is to study for a specified region; a. the relationships between the topographic parameters like length, area etc. b. the relationships between topographic and hydrological characteristics, particularly between i) area and average annual monsoon runoff, and ii) area and average annual peak flood.

1.3 Significance of the Study:

1. For a region in North India topographic relationships are being estimated perhaps for the first time.
2. The stream flow observations are available only for a small number of streams. By correlating hydrologic characteristics with physiographic characteristics, it is possible to estimate the hydrologic characteristics of ungauged watersheds in the region.
3. Since regression relationships are used, they will also indicate the confidence interval for any hydrologic estimate derived from regression relationships, thus indicating the reliability of empirical estimation.

1.4 Scope of the Study:

The scope of the study is limited to the following:

1. 1 inch = 1 mile maps are needed for estimating geomorpholocal paramaters of the basin. Since they are not available

for the study, only topographical characteristics that are avilable are used in the study.

2. Topographic data were available for 63 basins. They were all used in deriving the relationship between catchment area and length of stream .
3. Hydrologic data were available only for 12 stations. Hence hydromorphological relationships can be derived only on the basis of these limited data.
4. As only around six years of seasonal runoff data and annual peak runoff (daily value) were available, the runoff parameters studied are respectively average annual monsoon runoff and average annual peak runoff calculated from the limited data for around six years.

1.5 Details of the Report.

The report is presented in the following sequence:

1. As the study uses regess-ion analysis extensively, simple and multiple linear regression and correlation analyses are briefly described (Chapter - 2).
2. Geomorphological characteristics of a basin are briefly introduced. In the absence of data, physiographic parameters are used in the study. The relationships between length of main channel and catchment area for basin in the region are derived. The relationships for four subregions also are derived (Chapter-3).
3. The relationships between basin areas and respectively the

average annual monsoon runoff and average annual peak flood are derived for the region as a whole and for two subregions (Chapter - 4).

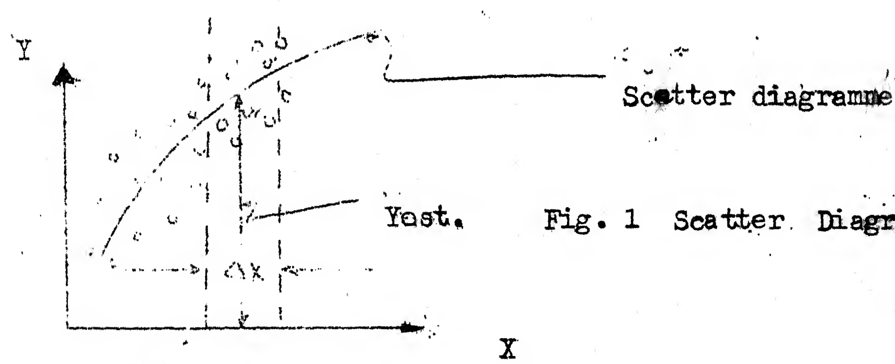
4. The conclusion from this study, suggestions for future studies etc. are finally presented (Chapter - 5).

CHAPTER - 2

REGRESSION ANALYSIS IN HYDROLOGY

2.1 GENERAL :

Hydrologic variables are generally random in nature and hence it is possible to analyse their frequency characteristics and make probabilistic prediction. It is sometimes possible that random variable Y in which one is interested is functionally related to another variable X which can be observed and measured . In this case, it is possible to make use of functional relationship between the dependent random variable Y and the independent random variable X, and to predict much more definitively the confidence interval for Y on the basis of the observed value of X. In the ideal case the functional relationship may be unique. Practically, however, because of errors in observation, analysis and approximation in the mathematical relationship, there may be some scatter in the actual observations about the ideal relationship; when dependent random variables versus independent random variables are plotted on the graph sheet the diagram obtained is called "the scatter diagramme". It has been observed from the scatter diagramme that it is possible to judge roughly whether they will follow a straight path or a curvilinear path.



Simple regression

Fig. 1 Scatter Diagramme.

By regression (20) of Y on X is meant the conditional expectation of Y given X. Thus given X, the estimate of Y by regression implies the average value of Y over the interval ($X-\frac{\Delta x}{2}$, $X + \frac{\Delta x}{2}$), where ΔX is a small interval. Thus $Y_{est}/X_i = \frac{1}{p}\sum Y_i$ for all points such that $X_i - \frac{\Delta x}{2} < X_i < X_i + \frac{\Delta X}{2}$, where p is the number of points and ΔX is sufficiently small so that Y does not vary much over ΔX and yet large enough to include a large number of points. It should be noted that regression of Y on X is generally different from the regression of X on Y. If there is a unique relationship between Y and X, then all observations will lie on the curve; otherwise there will be a scatter of points about the fitted curve. Correlation refers to the degree of association between the variables. In the case of exact functional relationship, there is a perfect association between the variables. The correlation in the case of scattered points is smaller. Theoretically there is zero correlation between independant random variables.

2.2 Simple and Multiple Linear Regression.

2.2.1 Simple linear Regression: Mathematically, simple linear regression can be written (20) as

$$Y = A + BX + \epsilon \quad \ldots\ldots\ldots 5$$

where Y is dependant random variable; and X is an independant variable, A and B are called regression constants or regression co-efficients and ϵ is the error in estimation.

2.2.2 Multiple Linear Regression (4,20,21). When two or more independant variables are related with a dependant variable and if the relationship be linear then the multiple regression equation is obtained as

$$Y=A+B_1X_1+B_2X_2+ \ldots + B_mX_m + \epsilon \quad \ldots\ldots\ldots 6$$

where Y is the dependant random variable, $X_1, X_2 \dots X_m$ are the m independant random vriables; A, B_i, with i = 1,...., m are referred to as multiple regression coeffiecents, and ϵ is the error in estimation.

Let, $Z_i = X_i - \bar{X}$ 6a. and $Z_o = Y_i - \bar{Y}$ .... 6b.

where the sign "‾" signifies the average of X_i's and Y_i's . Then the equation to be fitted is

$$Z_o = B_1 Z_1 + B_2 Z_2 + \dots + B_m Z_m + \epsilon \quad \dots\dots \quad 6c.$$

with $Z_o = Y - \bar{Y}$ .... 6d.

2.3 Regression Analysis:

2.3.1 Simple Linear Regression Analysis: From 2.2.1, a simple linear regression relationship is of the form

$$Y = A + BX + \epsilon \quad \dots\dots\dots\dots \quad 5$$

(20) Regression analysis consists in estimating the value of A and B and the characterestics of ϵ from observed data, and validating the relationship. Let the sample consist of N pairs of values (X_i, Y_i) with i = 1,2 ....., N and Y_i is the observation corresponding to X_i.

Let

$$Y_{est} = A + BX_i \quad \dots\dots\dots\dots \quad 7.$$

Then the error of estimate $\epsilon_i = Y_i - Y_{est}$ .... 7a.

i.e $\epsilon_i = Y_i - (A + BX_i)$ .... 7b .

where A and B are constants to be determined by a suitable procedure, here in, the method of least squares. Method of least squares refers to the process of obtaining the regression coefficients so that the sum of the squared errors is a minimum.

Now let , $S_o^2 = \sum_{i=1}^{N} \left(Y_i - Y_{est.}\right)^2 = \sum_{i=1}^{N} \left\{Y_i - \left(A + BX_i\right)\right\}^2 \ldots$ 7c.

If S_o^2 is to be a minimum, then, $\frac{\partial S_o^2}{\partial A} = 0$ and $\frac{\partial S_o^2}{\partial B} = 0$. Let $\bar{X}$ and $\bar{Y}$ represent the mean of X_i's and Y_i's respectively; also let,

$\Delta X_i = X_i - \bar{X}$ .... 8a. and $\Delta Y_i = Y_i - \bar{Y}$ .... 8b.

Hence on applying the method of least squares, it can be shown that

$$B = \sum_{i=1}^{N} \Delta X_i \Delta Y_i / \sum_{i=1}^{N} (\Delta X_i)^2 \quad \ldots\ldots\ldots\ldots\ldots 9.$$

Also

$$A = \bar{Y} - B\bar{X} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 10$$

Hence, from given data of X_i and Y_i, with $i = 1,2, \ldots\ldots\ldots, N$; B and A may be estimated from equations 9 and 10 respectively in that order .

2.3.2 Correlation: The degree of relationship that exists between the variables Y and X is measured by the correlation coefficient

$$r = \sum_{i=1}^{N} \Delta X_i \Delta Y_i / \sqrt{\sum_{i=1}^{N} (\Delta X_i)^2 \sum_{i=1}^{N} (\Delta Y_i)^2} \quad ..11.$$

$$\text{or} \quad r = B \frac{S_x}{S_y} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 11a.$$

where $S_x = \sqrt{\dfrac{\sum_{i=1}^{N} (\Delta X)^2}{N-1}}$ .... 12.

and $S_y = \sqrt{\sum_{i=1}^{N} (\Delta Y)^2 / N-1}$ .... 13 .

The value of r lies between - 1 and + 1. The negative and positive signs show that the value of Y respectively decreases or increases as X increases.

2.3.2 Variation About the Regression Line : According to (21), the error ϵ_i of the estimate of Y from the actual observations Y_i has a mean value of zero and is measured by its standard deviation which is referred to as the standard error of estimate $S_{y/x}$ or the standard deviation of the residuals S_o,

$$S_e^{\,2} = S_{y/x}^2 = \frac{N-1}{N-2}\, S_y^{\,2}\,(1-r^2) \ldots\ldots\ldots\ldots\ldots\ldots \quad 14.$$

$$= \frac{N-1}{N-2}\,(S_y^{\,2} - B^2 S_x^{\,2}) \ldots\ldots\ldots\ldots\ldots \quad 14a.$$

Consider the variance of **y**. When nothing is known about **x**, the variance of y is equal to $S_y^{\,2}$. However, for known value of x, the standard error of estimate is reduced to $S_e = S_{y/x}$. The reduction in variance $B^2 S_x^{\,2}$ is due to the variance that is accounted for regression. Thus when there is an approximate functional relationship between y and x, and is known, y can be predicted more accurately i.e with a smaller standard error of estimate than otherwise.

2.3.4 Tests for Significance of Regression Coefficients: The standard deviation of the regression coefficient B is given by $S_b = \dfrac{S_{y/x}}{S_x\sqrt{N-1}}$ ..15.

A t- test using the statistic $t = \dfrac{|B-\beta|}{S_b}$ .... 15a.

may be made to test whether the sample estimate B is significantly different from a population value β, at the given significance level with N -2 degrees of freedom.

For the intercept A. the standarised normal variable is given by

$$t = \frac{r\,(A-\alpha)}{B}\sqrt{\frac{N-2}{(1-r^2)\,(S_x^2+\bar{X}^2)}} \ldots\ldots\ldots\ldots\ldots\ldots \quad 16.$$

where α is the population value of the intercept. For a given confidence level, the significance of the difference between A and α can be tested. In the absence of any other information α and β are generally assumed to be zero.

2.3.5 Simple Exponential Regression: Consider an equation of the

form

$$U = CV^{B}\,10^{\epsilon} = 10^{A}\,10^{B\,\mathrm{Log}V}\,10^{\epsilon} \quad \ldots\ldots\ldots\ldots \quad 17.$$

where U,V are respectively dependent random variable and independent variable, C, B are constants, and, ϵ is the term for measuring error in estimate. The above equation is ~~referred~~ referred to as a simple exponential equation. It can be transformed to a linear equation by taking logarithm on both sides

$$\mathrm{Log}\ U = \mathrm{Log}\ C + B\ \mathrm{Log}\ V + \epsilon \quad \ldots\ldots\ldots \quad 18.$$

Let us assume, Log U = Y, Log V = X ; and Log C= A

Hence the above equation can be expressed as a simple linear regression equation

$$Y = A + BX + \epsilon \quad \ldots\ldots\ldots\ldots \quad 5.$$

Minimising the sum of the squares of deviation of Y from Y_{est} the regression coefficients A and B can be calculated as before. This is equivalent to minimisation of the sum of relative errors for the original variable U.

2.3.6 Confidence Bands: The confidence interval is defined (1) as an interval around the computed value within which a given percentage of values of a large number of samples is expected to fall. The confidence interval, for example, at 90% level means that out of 100 samples of equal size, it is expected that 90 percent values of a parameter would be inside that interval. The confidence limits define the boundaries of the confidence interval. If the computed parameter falls inside the selected confidence limits it is considered to be not significantly different from the assumed populations value at the given level of confidence. The selection of level is made either by convention or by

judgement.

In hydrology, the limits are generally chosen around 90 or 95 percent. Actually, the errors are t - distributed. However, assuming a large sample size and normal distribution of errors, The confidence interval is given approximately by $\pm 1.64\sigma_\epsilon$ for 90% confidence level i.e

$$\text{Prob}\ (-1.64\sigma_\epsilon < \epsilon < 1.64\sigma_\epsilon) = 90\% \quad \ldots\ldots\ 19.$$

Therefore, $Y = A + BX \pm 1.64\sigma_\epsilon$ ....20.

$$\text{i.e Prob}\ (A + BX - 1.64\sigma_\epsilon < Y < A + BX + 1.64\sigma_\epsilon) = 90\% \quad \ldots\ldots\ 21.$$

In case the actual relationship is exponential, say equation 17, then the corresponding 90% confidence interval will be

$$(CV^B\, 10^{-1.64\sigma_\epsilon} < U < CV^B\, 10^{+1.64\sigma_\epsilon}) \quad \ldots\ldots\ 22.$$

2.3.7 Steps in Linear Regression and Correlation Analysis: The following are the steps in linear regression analyses :

i. Scatter diagramme can be prepared from given hydrologic data.

ii. From the scatter diagramme, the type of relationship between the variables can be ascertained .

iii. Transformation procedures can be used if necessary to transform the variables so that a linear regression may be used.

iv. Computations can be made a. for the basic measures describing the linear relationship and b. for making required forecast estimates; and finally the confidence interval may be derived.

2.3.8 Limitationsof Regression Analysis: Regression analysis is based on a number of assumptions. Some of the major assumptions (20) are presented here.

i. The independent variables are measured without any error.

ii. The errors for the different observation are statistically independant.

iii. The probability distributions of all variables and errors are normal distributions.

iv. The variance of the error is approximately constant and is independent of the variables.

2.3.9 Conclusion: In this chapter (20) only basic concepts and methods of simple linear regression and correlation analyses have been briefly described. Regression analysis may be used to estimate missing hydrologic data and/for extending smaller length of records on the basis of longer records of a adjacent stations or related phenomena; for empirically estimating the variability of hydrologic parameters and subsequently making fore casts for ungauged basins.

CHAPTER - 3

GEOMORPHOLOGICAL RELATIONSHIPS

3.1 INTRODUCTION :

Quantitative geomorphological analysis (1,2,3) deals with measuring and quantitatively defining physical characteristics of a drainage basin. Two general classes of descriptive numbers are i. linear scale measurements whereby geometrically analogous units of topography can be compared as to size; and ii. dimensionless numbers, usually angles or ratios of length measures, whereby the shapes of analogous units can be compared irrespective of scale. Systematic description of the geometry of a drainage basin and its stream channel system requires measurement of linear aspects of the drainage networks, areal aspects of the drainage basin, and relief (gradient)aspects of channel network and contributing groundslopes. The first two categories of measurement are planimetric, whereas the third category treats the vertical inequalities of the drainage basin forms.

The physical laws of mechanics and hydraulics were used by Horton in a pioneering and comprehensive study (8). Here Horton revealed a consistent pattern under which stream systems develop and to which they continually adjust. He showed that the number of streams, the length of streams and slopes of streams were all related consistently to stream order through any existing stream system. Later revisions to the Horton stream ordering system were made by Strahler (24). The smallest fingertip tributaries are designated as first order stream.

When two first order streams join a channel segment of second order is obtained; where two second order streams join, a segment of third order is formed and so on. Horton also showed that the order number of any particular stream is directly proportional to the relative watershed dimensions, channel size and stream discharge at that particular stream. He also defined bifurcation ratio as the ratio of the number of stream segments at a particular order to the number of stream segments in the next higher order. From this he derived that the number of stream segments of each order form an inverse geometric sequence with the other number.

Horton postulated that the length ratio which is defined as the ratio of mean length $\bar{L}u$ of segment of order u to mean length of segment of the next lower order $\bar{L}u-1$ tends to be a constant throughout the successive orders of a watershed. He was, therefore, able to state the law of stream lengths, that the mean length of stream segment of each of the successive orders of a basin tend to approximate a direct geometric sequence in which the first term is the average length of segments of the first order:

$$\bar{L}u = \bar{L}_1 R_1^{u-1} \qquad \text{.......................... 23.}$$

If the law of stream lengths is valid, a plot of logarithm of stream length (ordinate) as a function of stream order (abscissa) should yield a set of points lying essentially along a straight line. As with the law of stream number, the law of stream length is essentially an exponential function defined only for integer values of independent variable. Assuming the validity of the laws of stream lengths and basin

areas, in which both properties are related by an exponential function with order, length should related to area by a power function. Morisawa (16) plotted both logarithm of mean stream length and logarithm of cummulative length against logarithm of basin area for each order of representative basins of Appalachian Plateau Province, obtaining highly linear relationships. Area of a given watershed or drainage basin, a property of the square of length is a prime determinant of total runoff and sediment yield and is normally eliminated as a variable by reduction to unit area, as in annual sediment loss in acreft/sq.mile in F.P.S. system.

Drainage density is defined as the ratio of the total stream length to the bas-in area. It can be regarded as the prime indicator for linear scale measurement of land form elements in stream eroded topography. It may be thought as an expression of the closeness of spacing of elements. In general low drainage density is associated with regions of highly resistant or highly permeable sub-soil materials under dense vagetative cover and where relief is low. High drainage is favoured in regions of weak or impermeable subsurface material, sparse vegetation and mountaineous relief.

Another geomorphological parameter is relief from which Schumm (22) found that sediment loss/ unit area is closely correlated with relief ratio. Also others (10) showed that the ratio yielded a higher correlation with sediment delivery rate then did relief and length related variables. It was also shown that relief ratio may prove useful in estimating sediment yield if the appropriate parameters for a given climatic province are once established. Moreover, it gave

a much close correlation than did other individually treated geometrical factors of length with ratio of basin, sediment contributing area, basin relief alone or average landscape.

As the soil and landform are moulded by the environment and particularly by the hydrologic cycle, the hydrologic characterestics of the basin and the geomorpholigic characterestics of the basin should be closely related. Hence when hydrologic data are scaree it may be possible to establish a correlation between available hydrologic and geomorphologic data for basins in any region and use it for estimating hydrologic characteristics of basins in the same region with limited or no data.

3.2 **DATA AVAILABLE:-**

The following data have been collected for the study.

a. Topographic Data:

i. 1 inch =8 miles map of a region in North India with a contour interval of 10 meters, and,

ii. lengths of main channel and area of 63 basins in the above region.

b. Hydrologic Data:- The following stream flow data are available for 12 basins in the above region.

i. Daily discharge data during the monsoon season from the year of 1968 to 1973.

ii. Total discharge in the monsoon season from 1968 to 1973; and,

iii. Maximum discharge in the monsoon period from 1968 to 1973.

.3 RELATIONSHIP BETWEEN THE CATCHMENT AREA AND THE STREAM LENGTH.

Toposheets to the scale of 1 inch = 1 mile are necessary for estimation of gemorphological characteristics. They are not available. Hence it is proposed to use the length of main channel L and the watershed area A_d, as the topographic characteristics of the basins. It is proposed to study the statistical relationship, if any, between the length of the main channel L, and the area A_d, of the basin using the data for all the 63 basins. As mentioned in Sec. 3.1, the following equation generally holds good;

$$A_d = CL^n \qquad \ldots\ldots 24.$$

where C and n are empirical constants. Hence, using logarithmic transformation, the above equation can be linearized to

$$\text{Log } A_d = \text{Log } C + n \text{ Log} L. \qquad \ldots\ldots 25.$$

Using the procedure indicated in chapter 2, it is possible to estimate the regression coefficents log C and n in the above equation.

3.3.1 Analysis for the Over-all Region: The data and the results of analysis for estimating the relationship between the basin area and channel length are indicated in Table 1. Column1 indicates the serial number of draniage basins; the second column indicates the code letter for basins which depends on the sub- region to which the basin belongs; and columns 5 and 6 indicate the logarithmns of drainage area and stream length respectively, denoted by Y and X. Let the deviation from the means of Y and X be respectively ΔY and ΔX, namely $Y = Y - \bar{Y}$, $X = X - \bar{X}$; columns 7 and 8 contain ΔY and ΔX. It may be noted that the sum of the ΔY and ΔX should respectively be equal

to zero, expect for any roundoff error in calculating the means. Columns 9, 10 and 11 respectively contain the values of cross-products $\Delta X \Delta Y$ and the squares of ΔY and ΔX. The last row gives the sum of all the values in given column.

From the tabular values the coefficients of regression equation can be obtained. The correlation coeffient, standard error of estimate are also be computed from it.

The same procedure has to be carried out for all the sub-regions separately. With the results thus obtained, a comparative study has to be made so as to determine whether all sub-regions are significantly different from the over all region at some predefined, say 90% confidence level.

TABLE-1. REGRESSION ANALYSIS BETWEEN STREAM LENGTH AND CATCHMENT AREA (OVERALL REGION).

Serial No.	CODE NUMBER	LENGTH	AREA	LOGARITHM OF LENGTH, X	LOGARITHM OF AREA, Y	ΔY	ΔX	$\Delta X \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	1_1	38.72	176.12	1.5879	2.2458	.7043	.5025	.3542	.4962	.2528
2.	1_2	11.84	15.54	1.0735	1.1914	-.3501	-.0119	.00416	.1226	.00014
3.	1_3	16.00	51.80	1.2041	1.7143	.1728	.1187	.02051	.02985	.01409
4.	1_4	10.88	36.26	1.0367	1.5594	-.0179	-.0487	-.00087	.00032	.00237
5.	1_5	9.6	12.95	0.9823	1.1124	-.4291	-.1031	.04424	.00184	.01063
6.	1_6	32.00	129.5	1.5051	2.1124	.3709	.4197	.1556	.1375	.1761
7.	1_7	40.00	207.20	1.6021	2.3164	.7749	.5167	.4003	.6003	.2669
8.	1_8	12.8	36.26	1.1072	1.5594	.0179	.0218	.00036	.00032	.00048
9.	1_9	10.40	18.13	1.0170	1.2584	.7169	-.0684	-.04904	.51390	.00468
10.	1_{10}	14.40	33.67	1.1584	1.5271	-.0144	.0730	-.00105	.00021	.00533
11.	1_{11}	48.00	310.80	1.6812	2.4925	.9510	.5958	.5666	.90440	.35500
12.	1_{12}	12.00	31.08	1.0792	1.4925	-.0490	-.0062	.00304	.00240	.00004
13.	1_{13}	11.20	46.62	1.0453	1.6686	.1271	-.0401	-.00509	.01615	.00161
14.	1_{14}	8.00	19.43	0.9031	1.2885	-.2530	-.1823	.04613	.06400	.03317
15.	1_{15}	16.00	20.72	1.2041	1.3164	-.2251	.1187	-.02673	.05067	.01409
16.	1_{16}	29.28	234.91	1.4666	2.3709	.8294	.3812	.3161	.68800	.14530

Continued.

17.	1_{17}	19.52	53.10	1.2904	1.7251	.1836	.2050	.03764	.03371	.04204
18.	1_{18}	12.32	44.68	1.0906	1.6501	.1086	.0052	.00056	.01180	.00003
19.	1_{19}	11.52	28.49	1.0615	1.4547	-.0868	-.0239	.00207	.00753	.00057
20.	1_{20}	41.60	259.00	1.6191	2.4133	.8718	.5337	.4652	.76000	.28480
21.	1_{21}	3.2	2.50	0.5051	0.3979	-1-.1436	-.5803	.6637	1.30800	.33670
22.	1_{22}	15.20	26.00	1.1818	1.4150	-.1265	.0964	-.0122	.01601	.00929
23.	1_{23}	29.60	119 .14	1.4713	2.0457	.5042	.3859	.1795	.2552	.12670
24.	1_{24}	12.80	26.00	1.1072	1.4150	-.1265	.0218	-.00276	.01601	.00048
25.	1_{25}	23.36	31.08	1.3685	1.4925	-.04900	.28310	-.01388	.00240	.08017
26.	1_{26}	48.00	119.14	1.6812	2.0759	.53440	.59580	.31840	.28550	.3550
27.	1_{27}	4.00	2.00	0.6021	0.3010	-1.2405	-.48330	.59950	1.5390	.23350
28.	2_{1}	24.00	129.50	1.3302	2.1124	.5709	.2448	.1397	.3260	.06006
29.	2_{2}	8.00	23.31	0.9031	1.3675	.1740	-.1823	-.03172	.03027	.03324
30.	2_{3}	8.00	20.72	0.9031	1.3164	-.2251	-.1823	.04104	.05058	.03324
31.	2_{4}	9.60	25.90	0.9868	1.4133	-.1282	-.0986	.01264	.01644	.00973
32.	2_{5}	13.76	60.22	1.1386	1.7797	.2382	.0523	.01268	.05675	.00283
33.	2_{6}	19.20	56.98	1.2833	1.7557	0.2142	0.1979	.04239	.04587	.03917
34.	2_{7}	12.80	36.26	1.1072	1.5594	0.0179	0.0218	.00049	.00032	.00047

Continued

35.	2_8	12.88	80.13	1.1100	1.2584	-.2831	.0246	-.00697	.08017	.00061
36.	2_9	10.40	31.08	1.0170	1.4925	-.0490	-.0684	.0085	.00240	.00468
37.	2_{10}	24.00	222.74	1.3802	2.3478	0.8063	.2948	.2377	0.6501	0.08690
38.	2_{11}	4.80	36.77	0.6812	1.5655	.0240	-.4062	-.00970	.00058	.16340
39.	2_{12}	3.76	1.86	0.5752	0.2695	-1.2720	-.5102	.6491	1.6180	0.2604
40.	2_{13}	2.40	6.86	0.3802	0.8363	-.7052	-.7052	.4973	.4973	.4973
41.	2_{14}	1.52	7.23	0.1818	0.8597	-.6818	-.9036	.6160	.4647	.8166
42.	2_{15}	2.40	7.48	0.3802	0.8739	-.6676	-.7052	.4708	.4457	.4973
43.	2_{16}	3.20	3.88	0.5051	0.5888	-.9530	-.5803	.5530	.9082	.3367
44.	2_{17}	2.40	3.21	0.3802	0.5051	-1.0364	-.7052	0.7303	1.0633	0.4973
45,	2_{18}	1.12	5.18	0.0492	0.7143	-.8272	-1.0362	0.8567	.68430	1.0730
46.	2_{19}	2.08	1.92	0.3181	0.2833	-1.2582	-.7673	0.9651	1.58200	0.5902
47.	3_1	57.12	60.37	1.7568	1.7808	.2392	.6714	.1606	.05723	.4508
48,	3_2	64.00	130.33	1.8062	2.1149	.5734	.7208	.41133	.32890	.51950
49.	3_3	19.20	73.30	1.2833	1.8651	.3236	.1979	.06404	.10470	.03917
50.	3_4	19.09	58.33	1.2808	1.7659	.2244	.1954	.04383	.05035	.03816
51.	3_5	32.32	134.68	1.5095	2.1291	.5876	.4241	.24920	.34510	.22750
52.	4_1	24.32	138.05	1.3860	2.1399	.5484	.3006	.1648	.30070	.09036

Continued.

53.	4_2	25.60	77.70	1.4082	1.8904	.3489	.3228	.1127	.12170	.1042
54.	4_3	23.00	119.14	1.3617	2.0754	.5344	.2763	.1477	.2855	.07635
55.	4_4	11.84	91.87	1.0735	1.9631	.4216	.0119	.00502	.1777	.00014
56.	4_5	26.56	105.67	1.4242	2.0237	.4822	.3388	.1633	.2325	.1148
57.	4_6	12.80	38.85	1.1072	1.5894	.0479	.0218	.00104	.00229	.00060
58.	4_7	16.00	38.85	1.2041	1.5894	.0479	.1187	.00569	.00229	.01409
59.	4_8	12.80	38.85	1.1072	1.5894	.0479	.0218	.00104	.00229	.00048
60.	4_9	44.16	284.99	1.6450	2.4548	.9133	.5596	.51110	.83410	.31320
61.	4_{10}	19.20	25.90	1.2833	1.4133	-.1282	.1979	.02537	.01644	.03917
62.	4_{11}	1.92	12.95	0.2833	1.1124	-.4291	-.8021	.34430	.18420	.64360
63.	4_{12}	4.32	12.82	0.6355	1.1079	-.4336	-.4499	.19510	.18800	.20240
		$\bar{X}$=1.0854	$\bar{Y}$=1.5415					13.1746	19.0208	10.6197

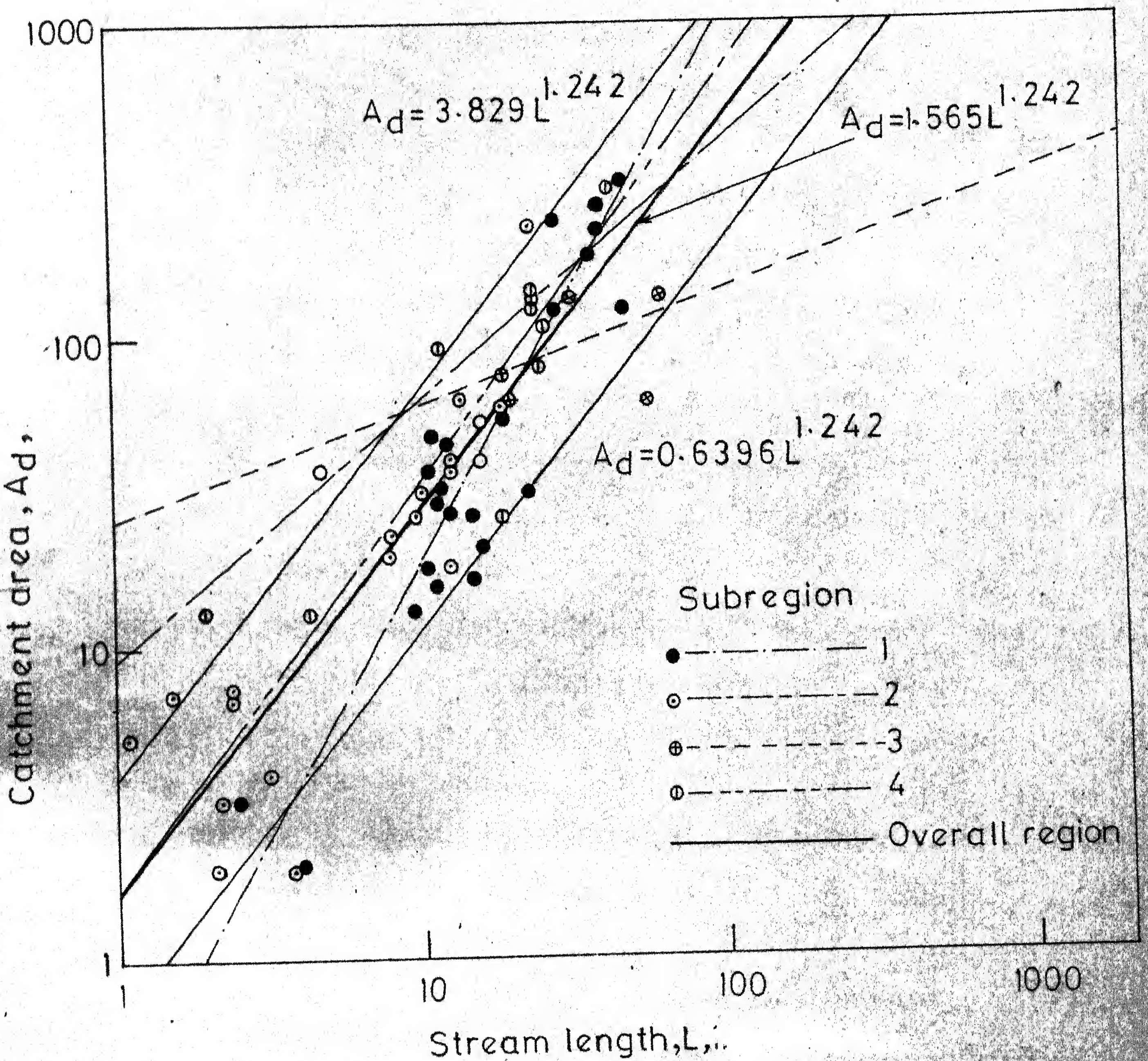


FIG. 2 REGRESSION RELATIONSHIP BETWEEN CATCHMENT AREA AND STREAM LENGTH (Over all region)

3.3.1 Analysis for Over-all Region.

From Table 1. the following results can be obtained

$\bar{X} = 1.0854$. $\bar{Y} = 1.5415$; $\sum \Delta X \Delta Y = 13.1746$; $\sum (\Delta X)^2 = 10.6197$;

$\sum (\Delta Y)^2 = 19.0208$.

Hence from eqs. 9 and 10, $A = 0.1945$; $B = 1.242$;

Whether the coefficient A is significantly different from $\alpha = 0$, is tested by using eqs. 16 with the help of eqs. 11 and 12. From eq.16, $t_A = 2.603$. But $t_{90\%;\ 61 d.f.} = 1.2956$. Hence $t_A > t_{90\%;\ 61 d.f.}$. This shows that A is significantly different from zero at 90% confidence level.

Whether the coefficient B is significantly different from $\beta = 0$, is tested by using eqs. 12, 14, 15 and 15a., $t_B = 173$, which is obviously greater than the value of $t_{90\%;\ 61 d.f.}$.

Hence, B is significantly different from zero at 90% confidence level.

Further from eq. 11, the value of correlation coefficient $r = 0.9055$; But, $r_{90\%;\ 61 d.f.} = 0.250$. Hence the value of r is significant at 90% confidence level.

Again, from eq. 14, $S_e = 0.2369$. Therefore regression equation for over-all region is given by

$$\text{Log } A_d = 0.1945 + 1.242 \text{ Log} L. \text{ Hence } A_d = 1.565 L^{1.242} \qquad \ldots 26.$$

From eq. 22, the 90% confidence bands can be estimated as follows:

$$\text{Prob } (0.6396 L^{1.242} < A_d < 3.829 L^{1.242}) = 90\% \qquad \ldots\ldots\ldots 27.$$

All the above results are also shown in Fig. 2.

TABLE -2. REGRESSION ANALYSIS BETWEEN STREAM LENGTH AND CATCHMENT AREA (SUBREGION -1)

Serial No.	CODE NO.	AREA	LENGTH	LOGARITHM OF AREA	LOGARITHM OF LENGTH	ΔY	ΔX	$\Delta X \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	1_1	176.12	38.72	2.2458	1.5879	0.6306	0.3793	0.2391	0.3976	0.14380
2.	1_2	15.54	11.84	1.1914	1.0735	-.4238	-.1351	0.1365	0.1796	0.01825
3.	1_3	51.80	16.00	1.7143	1.2041	0.0991	-.0045	-.00045	0.0982	0.00002
4.	1_4	36.26	10.88	1.5594	1.0367	-.0558	-.1719	0.09634	0.0031	0.02954
5.	1_5	12.95	9.60	1.1124	0.9823	-.5028	-.2263	0.1137	0.2528	0.05117
6.	1_6	129.50	32.00	2.1124	1.5051	0.4972	0.2985	0.1485	0.2473	0.08908
7.	1_7	207.20	40.00	2.3164	1.6021	0.7012	0.3935	0.2758	0.4916	0.15480
8.	1_8	36.26	12.80	1.5594	1.1072	-.0558	-.1014	0.0057	0.0031	0.01120
9.	1_9	18.13	10.40	1.2584	1.0170	-.3568	-.1916	0.0683	0.1273	0.03669
10.	1_{10}	33.67	14. 40	1.5271	1.1584	-.0881	-.0502	0.0044	0.0078	0.00250
11.	1_{11}	310.80	48.00	2.4925	1.6812	0.7773	0.4726	0.3673	0.6042	0.22320
12.	1_{12}	31.08	12.00	1.4925	1.0792	-.1227	-.1294	0.0159	0.0151	0.01675
13.	1_{13}	46.62	11.20	1.6686	1.0453	0.0534	-.1633	-.0087	0.0028	0.02669
14.	1_{14}	19.43	8.00	1.2885	0.9031	-.3267	-.3055	0.0998	0.1067	0.09330
15.	1_{15}	20.72	16.00	1.3164	1.2041	-.2988	-.0045	0.00134	0.8930	0.00002

Continued.

16.	1_{16}	234.91	29.28	2.3709	1.4666	0.7557	0.2580	0.1949	0.57100	0.06656
17.	1_{17}	53.10	19.52	1.7251	1.2904	0.1099	0.0818	0.0090	0.01210	0.00670
18.	1_{18}	44.68	12.32	1.6501	1.0906	0.0309	-.1180	-.0041	0.0012	0.01393
19.	1_{19}	28.49	11.52	1.4547	1.0615	-.1605	-.1471	0.0236	0.0258	0.02164
20.	1_{20}	259.00	41.60	2.4133	1.6191	0.7981	0.4105	0.3276	0.6371	0.16850
21.	1_{21}	2.50	3.20	0.3979	0.5051	-1.2173	-.7035	0.8561	1.4800	0.49500
22.	1_{22}	26.00	15.20	1.4150	1.1818	-.2002	-.0268	0.0054	0.0401	0.00620
23.	1_{23}	119.14	29.6	2.0457	1.4713	0.4305	0.2627	0.1131	0.1854	0.06900
24.	1_{24}	26.00	12.80	1.4150	1.1072	-.2002	-.1387	0.0203	0.0401	0.01030
25.	1_{25}	31.08	23.36	1.4925	1.3685	-.1227	0.1226	-.01961	0.0150	0.02559
26.	1_{26}	119.14	48.00	2.0759	1.6812	0.4607	0.4726	0.2177	0.2123	0.22320
27.	1_{27}	2.00	4.00	0.3010	0.6021	-1.3142	-.6065	0.7971	1.7270	0.3680
		$\bar{Y}$ =1.6152;	$\bar{X}$ =1.2086;			.0012	.0014	4.0945	8.3773	2.3768

3.5.2 **Analysis of Subregions:** It is proposed to test whether the relationship derived for the overall region holds for the subregion also. The details are given separately for each subregion.

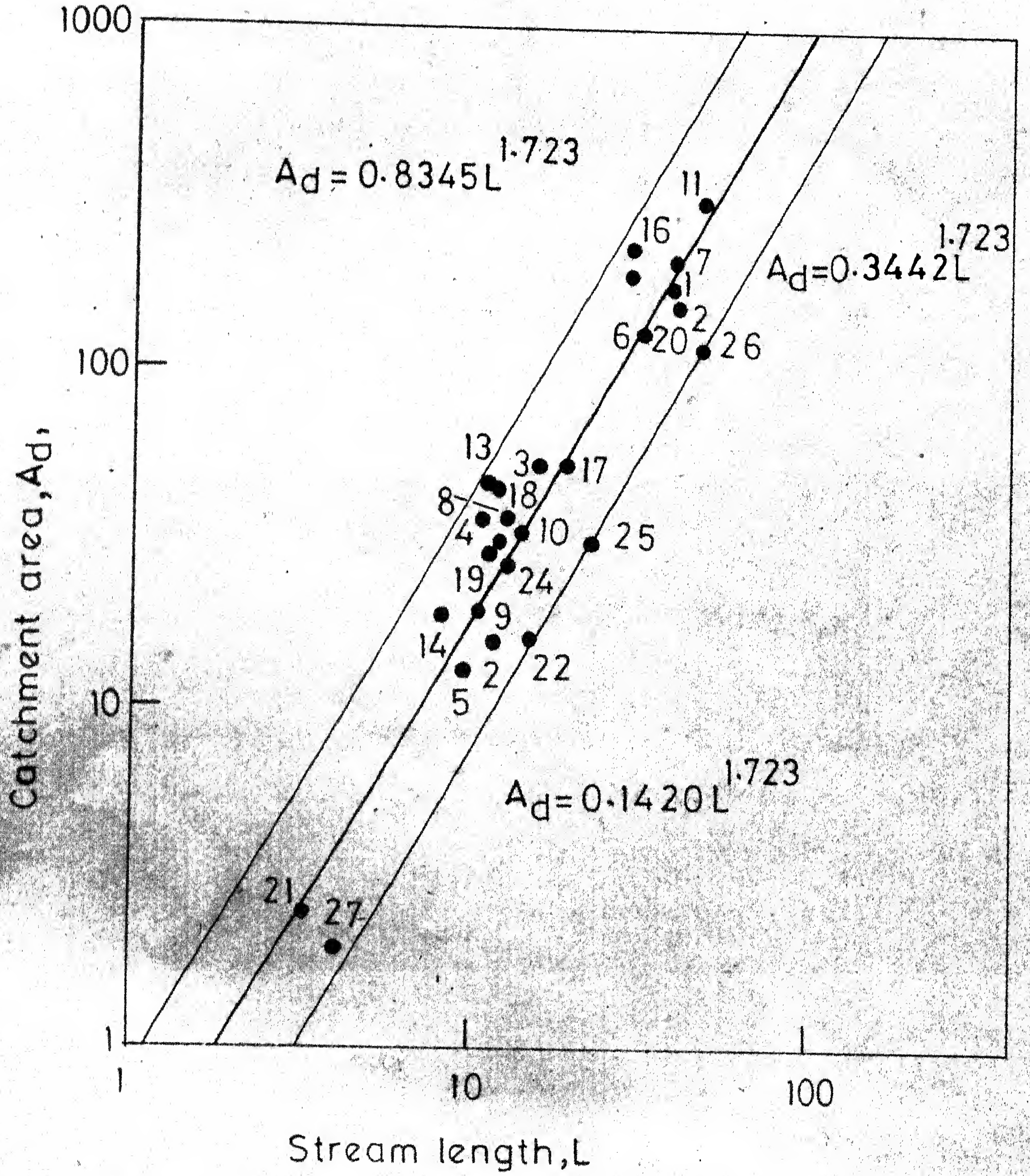


FIG. 3 REGRESSION RELATIONSHIP BETWEEN CATCHMENT AREA AND STREAM LENGTH (Sub region- 1)

3.3.2.1 Subregion 1: The data and calculations for subregion 1 are shown in Table - 2. From Table - 2. the following results can be obtained.

$$\bar{X} = 1.2086 \; ; \; \bar{Y} = 1.6152 \; ; \; \sum \Delta X \cdot \Delta Y = 4.0945 \; ; \; \sum (\Delta X)^2 = 2.3768;$$
$$\sum (\Delta Y)^2 = 8.3773.$$

Therefore from eqs. 9 and 10, $A_1 = -0.4658$; $B_1 = 1.723$.

Whether the coefficient A_1 is significantly different from $\alpha = 0.1945$, is tested by using eq. 16 with the help of eqs. 11 and 12. From eq.16 $t_{A_1} = 1.68$. But $t_{90\% \,;25d.f.} = 1.3163$. Therefore $t_{A_1} > t_{90\% \,;25d.f.}$, which shows that A_1 is significantly different from $\alpha = 0.1945$ at 90% confidence level.

Whether the coefficient B_1 is significantly different from $\beta = 1.242$, is tested by using eqs. 12, 14, 15, 15_a. From eq. 15_a, $t_{B_1} = 16.28$ which is obviously greater than the value of $t_{90\% \,;\, 25d.f.}$. Hence B_1 is significantly different from $\beta = 1.242$ at 90% confidence level.

Further, from eq. 11, the value of correlation coefficient, $r=0.9175$. But $r_{90\% \,;25d.f.} = 0.381$. Therefore the value of r is also significantly different from zero at 90% confidence leve.

Using eq. 14, the value of standard error of estimate Se = 0.2344.

Therefore regression equation for subregion 1 is $\text{Log } A_d = -0.468 + 1.723L$.

$$\text{or, } A_d = 0.3442L^{1.723} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad 28.$$

From eq. 22 the 90% confidence bands can be estimated in the following way

$$\text{Prob } (0.1420L^{1.723} < A_d < 0.8345L^{1.723}) = 90\% \quad \ldots\ldots\ldots\ldots \quad 29.$$

The regression equation and the confidence intervals are shown in Fig. 3.

TABLE - 3. REGRESSION ANALYSIS BETWEEN STREAM LENGTH AND CATCHMENT AREA (Subregion 2)

Serial No.	CODE LETTER	AREA	LENGTH	LOGARITHM OF AREA	LOGARITHM OF LENGTH	ΔY	ΔX	$\Delta X \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	2_1	129.50	24.00	2.1124	1.3802	0.90714	0.6086	0.5520	0.8226	0.3703
2.	2_2	23.31	8.00	1.3645	1.9031	0.16224	0.1315	0.02194	0.02631	0.01732
3.	2_3	20.72	8.00	1.3164	0.9031	0.11114	0.1315	0.01463	0.01237	0.01732
4.	2_4	25.90	9.60	1.4133	0.9868	0.20804	0.2152	0.04476	0.04367	0.04630
5.	2_5	60.22	13.76	1.7797	1.1386	0.57444	0.3670	0.2113	0.3299	0.1354
6.	2_6	56.98	19.20	1.7557	1.2863	0.55044	0.5117	0.2816	0.3030	0.2624
7.	2_7	36.26	12.8	1.5594	1.1072	0.35414	0.3356	0.1188	0.1254	0.1126
8.	2_8	18.13	12.88	1.2584	1.1000	0.05314	0.3384	0.01798	0.0028	0.1145
9.	2_9	31.08	10.40	1.4925	1.0170	0.28724	0.2454	0.09632	0.0825	0.1125
10.	2_{10}	222.74	24.00	2.3478	1.3802	1.14254	0.6086	0.6950	1.3040	0.3703
11.	2_{11}	36.77	4.80	1.5655	0.6812	0.36024	-.0904	-0.03256	0.1297	0.0082
12.	2_{12}	1.86	3.76	0.2695	0.5752	-0.93576	-0.1964	0.07433	0.8540	0.04260
13.	2_{13}	6.86	2.40	0.8363	0.3802	-0.36896	-0.3914	0.14420	0.13610	0.15320
14.	2_{14}	7.23	1.52	0.8597	0.1818	-0.34556	-0.5898	0.20370	0.11940	0.34780
15.	2_{15}	7.48	2.40	0.8739	0.3802	-0.33136	-0.3914	0.1296	0.10970	0.15320
16.	2_{16}	3.88	3.20	0.5888	0.5051	-0.61646	-0.2665	0.1644	0.3802	0.07103

Continued.

17.	2_{17}	3.21	2.40	0.5056	0,3802	-0.69966	-0.3914	0.2417	0.4896	0.1194
18.	2_{18}	5.18	1.12	0.7143	0.0492	-0.49096	-0.7224	0.3546	0.2410	0.5217
19.	2_{19}	1.92	2.08	0.2833	0.3181	-0.92196	-0.4535	0.4181	0.8500	0.1634
		$\bar{Y} = 1.20526$; $\bar{X} = 1.7716$;				+0.0003	+.00006	4.1106	6.3837	3.1394

2.3.2.2 Subregion 2: The data and calculations for subregion2 are shown in Table - 3. From Table - 3, the following results can be obtained

$\bar{X} = 1.7716$; $\bar{Y} = 1.20526$; $\sum \Delta X \, \Delta Y = 4.1106$; $\sum (\Delta Y)^2 = 6.3837$; $\sum (\Delta X)^2 = 3.1394$

Therefore from eqs. 9 and 10, $A_2 = 0.195$; $B_2 = 1.309$.

Whether the coefficent A_2 is significantly different from $\alpha = 0.1945$, is tested by using eq. 16 with the help of eqs. 11 and 12. From eq. 16 $t_{A_2} = 0.0042$; But $t_{90\%; 17 d.f.} = 1.334$. Hence $t_{A_2} < t_{90\%; 17 d.f.}$, which shows that A_2 is not significantly different from $\alpha = 0.1945$ at 90% confidence level.

Whether the coefficient B_2 is significantly different from $\beta = 1.242$, is tested by using eqs. 12, 14, 15 and 15a. From eq. 15a. $t_{B_2} = 0.4776$; which shows that B_2 is not significantly different from $\beta = 1.242$ at 90% confidence level.

Further, from eq. 11 the value of correlation coefficient, $r = 0.9181$. But $r_{90\%; 17 d.f.} = 0.456$. Therefore the value of are is significantly different from zero at 90% confidence level.

using eq. 14, the value of standard error of estimate $Se_i = 0.2431$.

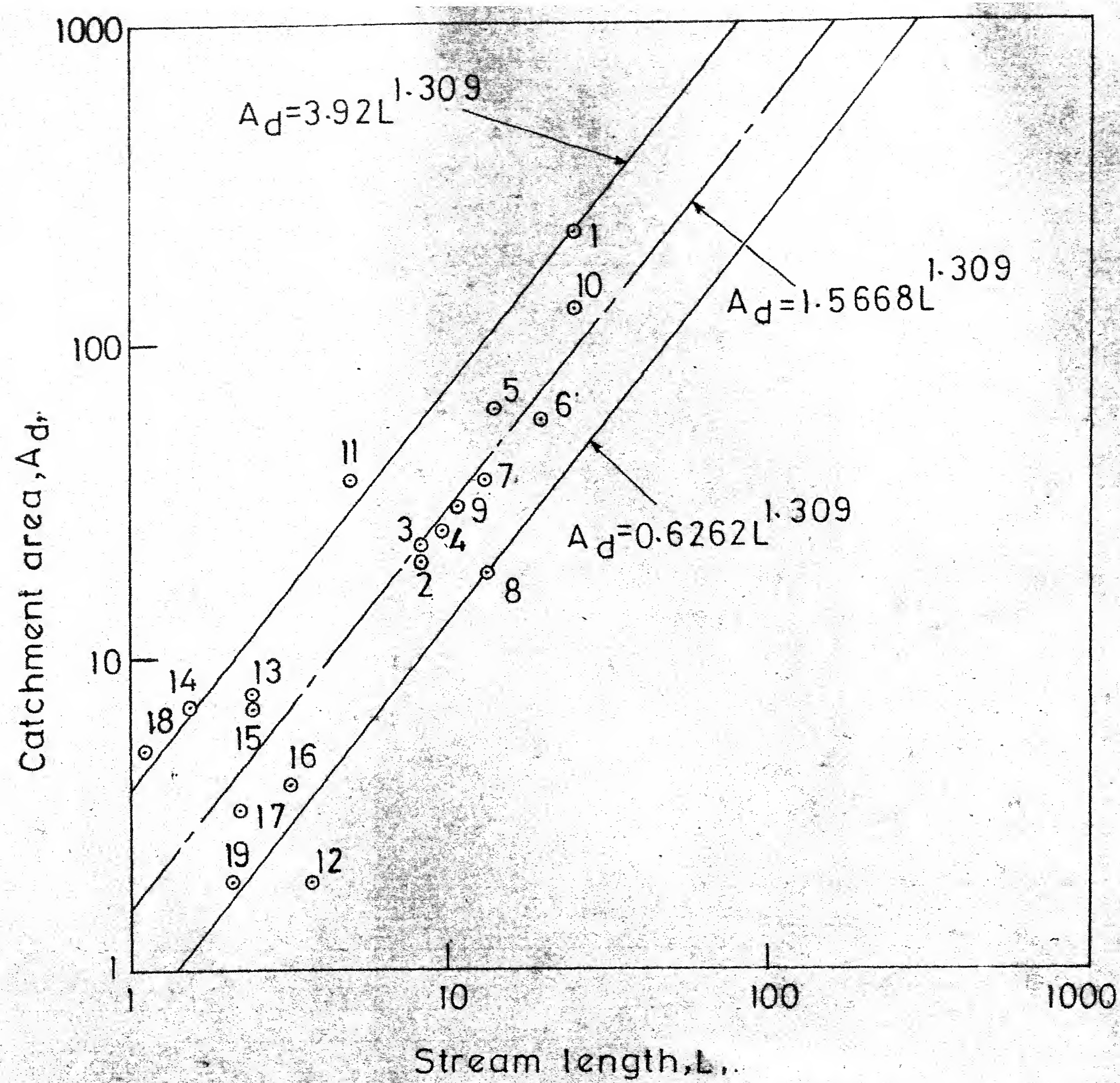


FIG.4 REGRESSION RELATIONSHIP BETWEEN CATCHMENT AREA AND STREAMLENGTH (Subregion-2)

Hence, $A_2 = 0.1945$ and $B_2 = 1.242$, as for the overall region seems to be satisfactory at 90% confidence level.

Considering the actual values of $A_2 = 0.195$ and $B_2 = 1.309$, calculated from the region the regression equation for the subregion 2 is given by, $\text{Log } A_d = 0.195 + 1.309 \text{LogL}$.

$$\text{Hence } A_d = 1.5668L^{1.309} \quad \ldots\ldots 30$$

From eq. 22, the 90% confidence bands can be estimated as follows:

$$\text{Prob } (0.6262L^{1.309} < A_d < 3.92L^{1.309}) = 90\% \quad \ldots\ldots 31$$

All the above results are shown in Fig. 4.

TABLE - 4. REGRESSION ANALYSIS BETWEEN STREAM LENGTH AND CATCHMENT AREA (Subregion 3).

Serial No.	CODE LETTER	AREA	LENGTH	LOGARITHM OF AREA	LOGARITHM OF LENGTH	ΔY	ΔX	$\Delta X \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	3_1	60.37	57.12	1.7808	1.7568	-0.15036	0.22948	-0.0345	0.0226	0.0529
2.	3_2	130.33	64.00	2.1149	1.8062	0.18374	0.27888	0.05193	0.0338	0.0778
3.	3_3	73.30	19.20	1.8651	1.2833	-0.06606	-0.24402	0.01610	0.0043	0.0592
4.	3_4	58.33	19.09	1.7659	1.2808	-0.16526	-0.24652	0.04080	0.0272	0.0610
5.	3_5	134.68	32.32	2.1291	1.5095	0.19794	-0.01782	-0.00260	0.0392	0.0003
		$\bar{Y} = 1.93116$;	$\bar{X} = 1.52732$			0	0	0.07173	0.1271	0.2512

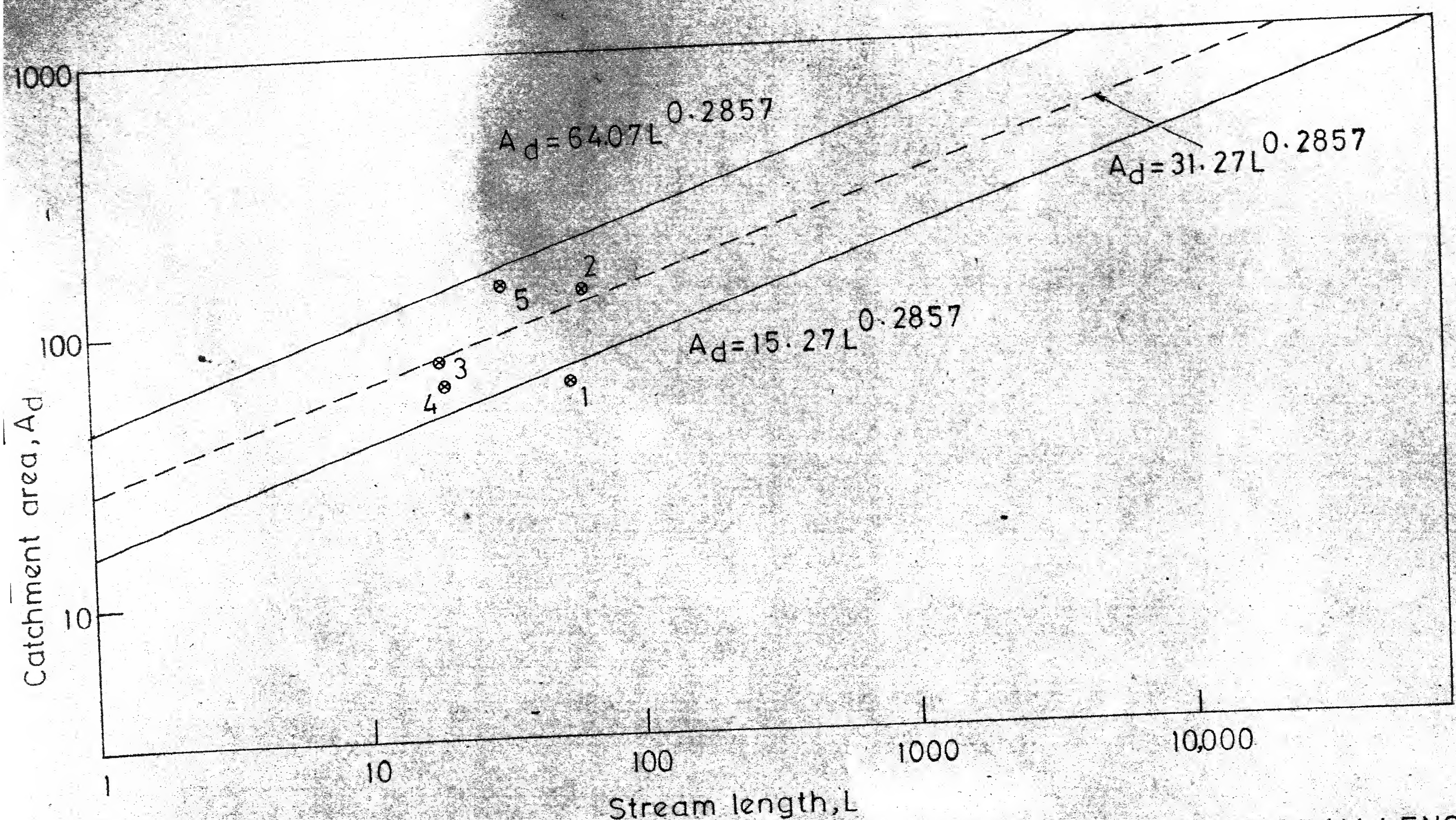


FIG. 5 REGRESSION RELATIONSHIP BETWEEN CATCHMENT AREA AND STREAM LENGTH (Sub region - 3)

3.3.2.3 Subregion 3: The data and calculations for subregion 3 are shown in Table 4. From Table -4. the following results can be obtained

$$\bar{X} = 1.52732;\ \bar{Y} = 1.93116;\ \sum \Delta X \Delta Y = 0.07173;\ \sum (\Delta X)^2 = 0.2512;$$
$$\sum (\Delta Y)^2 = 0.1271;$$

Hence, from eqs. 9 and 10, $A_3 = 1.4952$; $B_3 = 0.2857$;

Whether the coefficient A_3 is significantly different from $\alpha = 0.1945$, is tested by using eq. 16 with the help of eqs. 11 and 12. From eqs. 16, $t_{A_3} = 2.207$. But $t_{90\%;3d.f.} = 1.6377$. Hence $t_{A_3} > t_{90\%;3d.f.}$, which shows that A_3 is significantly different from $\alpha = 0.1945$ at 90% confidence level.

Whether the coefficient B_3 is significantly different from $\beta = 1.242$, is tested by using eqs. 12,14,15 and 15a. From eq. 15a. $t_{B_3} = 2.557$, which is greater than the value of $t_{90\%;3d.f.} = 1.6377$. Therefore B_3 is significantly different from $\beta = 1.242$ at 90% confidence level.

Further, from eq. 11, the value of correlation coefficient, $r = 0.4015$; but $r_{90\%;3d.f.} = 0.878$. Hence the value of r is not significant at 90% confidence level.

Using eq. 14, the value of standard error of setimate, $S_e = 0.2369$.

Therefore, regression equation for subregion 3,

$$\text{Log } A_d = 1.4952 + 0.2857 \text{LogL}, \text{ or } A_d = 31.27L^{0.2857} \qquad ..32.$$

From eq. 22, the 90% confidence bands can be estimated as follows:

$$\text{Prob } (15.27L^{0.2857} < A_d < 64.07L^{0.2857}) = 90\% \qquad \ldots\ldots\ldots\ldots33$$

All the above results are also shown in Fig. 5. It may be noted that in the case of subregion 3 the confidence interval is very wide compared to others. This may be cause of the small number of sample points available for regression analysis.

TABLE - 5. REGRESSION ANALYSIS BETWEEN STREAM LENGTH AND CATCHMENT AREA (Subregion 4).

Serial No.	CODE LETTER	AREA	LENGTH	LOGARITHM OF AREA	LOGARITHM OF LENGTH	ΔY	ΔX	$\Delta X \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	4_1	138.05	24.32	2.1399	1.3860	0.3941	0.22607	0.08910	0.1553	0.05112
2.	4_2	77.70	25.60	1.8904	1.4082	0.1446	0.24827	0.03590	0.0209	0.06166
3.	4_3	119.14	23.00	2.0759	1.3617	0.3301	0.20177	0.06661	0.1089	0.04071
4.	4_4	91.87	11.84	1.9631	1.0735	0.2173	-0.08643	-0.01878	0.04723	0.00747
5.	4_5	105.67	26.56	2.0237	1.4242	0.2779	0.26427	0.07343	0.07723	0.06982
6.	4_6	38.85	12.80	1.5894	1.1072	-0.1564	-0.05273	0.00825	0.02445	0.00278
7.	4_7	38.85	16.00	1.5894	1.2041	-0.1564	0.04417	-0.00691	0.02445	0.00195
8.	4_8	38.85	12.80	1.5894	1.1072	-0.1564	-0.05273	0.00825	0.02445	0.00278
9.	4_9	284.99	44.16	2.4548	1.6450	0.7090	0.48507	0.34380	0.5025	0.2352
10.	4_{10}	25.90	19.20	1.4133	1.2833	-0.3325	0.12337	-0.04102	0.1105	0.01522
11.	4_{11}	12.95	1.92	1.1124	0.2833	-0.6333	-0.87663	0.5551	0.4011	0.76850
12.	4_{12}	12.82	4.32	1.1079	0.6355	-0.6379	-0.52443	0.3350	0.4082	0.2749
		$\bar{Y} = 1.7458$;	$\bar{X} = 1.15993$;			0.0001	0.00004	1.2571	1.9053	1.5311

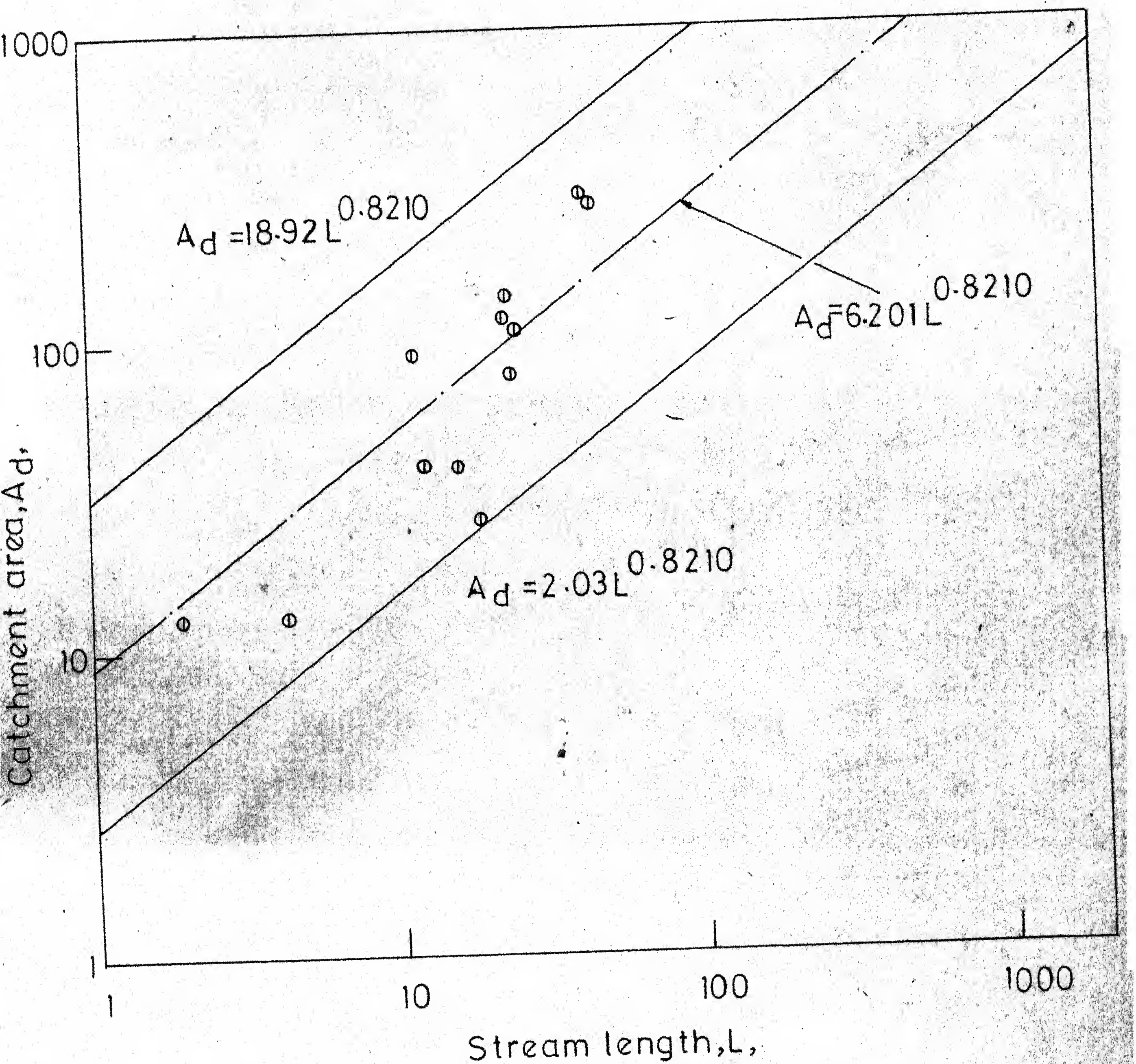


FIG.6 REGRESSION RELATIONSHIP BETWEEN CATCHMENT AREA AND STREAMLENGTH (Sub region-4)

3.3.2.4 Subregion 4. The data and calcuations for subregion 4 are shown in Table-5. From Table -5. the following results are obtained

$$\bar{X} = 1.15993;\ \bar{Y} = 1.7458;\ \sum \Delta X \, \Delta Y = 1.2571;\ \sum (\Delta X)^2 = 1.5311;$$
$$\sum (\Delta Y)^2 = 1.9053.$$

Hence from eqs. 9 and 10, $A_4 = 0.7935$; $B_4 = 0.8210$.

Whether the coefficient A_4 is significantly eifferent from $\alpha = 0.1945$, is tested by using eq. 16 with the help of eqs. 11 and 12, From eq. 16 $t_{A_4} = 27.43$. But $t_{90\%;\ 10d.f.} = 1.3722$. Hence $t_{B_4} > t_{90\%;\ 10d.f.}$, which shows that B_4 is significantly different from zero at 90% confidence level.

Further, from eq. 11, the value of correlation coefficient, $r = 0.6923$. But $r_{90\%;\ 10d,f.} = 0.576$. Hence the value of r is also significant at 90% level.

From eq. 14, the value of standard error of estimate, $Se = 0.2955$.

Hence, the regression equation for the subregion D is given by ,

$$\text{Log } A_d = 0.7985 + 0.8210 \text{ LogL. or, } A_d = 6.201 L^{0.8210} \quad \ldots 34.$$

Using equation 22, the 90% confidence bands can be estimated as follows: $\text{Prob}\ (2.03 L^{0.8210} < A_d < 18.92 L^{0.8210})\ 90\%$ .... 35 .

All the above results are also shown in Fig. 6.

3.3.3 Discussion of Results: From the results of subsection 3.3.2, it is seen that only for subregion 2 the relationship is not significantly different at 90% confidence level from that for the overallregion and those for regions 1,3and 4 are significantly different at 90% confidence level from that for the overall region. Hence the relationship for subregion 2 also is derived from its own data.

It is seen that an exponential relationship of the form $A_d = C\,L^n$, can be fitted for basins in the region. However each subregion has a different relationship and different confidence bands, and the results are listed below:

Subregion : 1 $A_d = 0.3442L^{1.723}$; Prob $(0.1420L^{1.723} < A_d < 0.8345L^{1.723}) = 90\%$.

Subregion : 2 $A_d = 1.5668L^{1.309}$; Prob $(0.6396L^{1.309} < A_d < 3.839L^{1.309}) = 90\%$.

Subregion: 3 $A_d = 31.27L^{0.2857}$; Prob $(15.27L^{0.2857} < A_d < 64.07L^{0.2857}) = 90\%$.

Subregion: 4 $A_d = 6.201L^{0.8210}$; Prob $(2.03L^{0.8210} < A_d < 18.92L^{0.8210}) = 90\%$.

CHAPTER - 4 .

HYDROMORPHOLOGICAL RELATIONSHIPS

4.1 GENERAL.

Generally hydrologic data are not available for large number of basins, but topographical and geomorphological data are available. Since the physiographic characteristics of a basin are dependent on hydrologic characteristics of the environment to which it is exposed, it is reasonable to expect some relationship between hydrologic and physiographic characteristics. In general, such relationships can be established on the basis of limited available data concerning both hydrologic and physiographic characteristics. For example, for the region under consideration, streamflow data are available only for 12 basins and that too for around 6 years. In case it is possible to establish hydromorphological relationships, it will then be possible to estimate the hydrologic characteristics of basins without data from the available topographic data and the hydromorphological relationships .

Without loss of generality it is proposed to use the area of the basins as the topographic characteristic in deriving empirical relationships. Since only six years of daily streamflow data during monsoon period are available for the basin the hydrologic characteristics to be studied as follows: i. The average annual monsoon runoff , and , ii. The average annual peak runoff .

It has been indicated in subsections 1.1.3 and 3.1, that relationships between the discharge and the drainage area are generally

of the form, $Q=R\,A_d^{S}$ ...... 36., where R and S are empirical constants to be determined by regression analysis. Hack (6) plotted average discharge in cfs. against drainage basin area in sq. miles on logarithmic paper for all gauging stations in the Potomac River basin and fitted a regression line with an exponent of 1.0, which shows that discharge is directly proportional to the drainage area. From this, he concluded that studies of relationship of basin area with respect to other variables such as, order, channel slope, channel width and stream length would apply by direct proportionality to average annual discharge as well.

Leopold and Miller (12) showed that for the Central New Mexico region, the discharge -area relationship can be best be described by the equation,

$\bar{Q} = 12A^{0.79}$ .... 37., where $\bar{Q}$ is the average annual peaks flood discharges, in cfs. and, A_d is drainage area in square miles. They were then able to combine the discharge area graph with an order area graph to show the relationship of discharge to stream order. A similar relationship has been observed between the peak flood and the drainage area for, e.g., Ryve's formula, Dickens formula (2,9) etc. Hence it is proposed to investigate whether .... exponential relationships indicated above can be derived for the basins in the region. As adequate data are not available for subregions 2 and 3, it is proposed to derive the relationships only for subregions 1 and 4.

TABLE -6. REGRESSION ANALYSIS BETWEEN AVERAGE ANNUAL MONSOON RUNOFF AND CATCHMENT AREA

(Overall Region)

Serial No.	CODE LETTER	MEAN ANNUAL DISCHARGE Q	AREA A_d	LOGARITHM OF Q	LOGARITHM OF A_d	ΔY	ΔX	$\Delta X \cdot \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	1_1	1278	176.12	3.1066	2.2458	-0.49165	-0.21596	-0.1062	0.2417	0.04662
2.	1_{16}	16744	234.91	4.2238	2.3709	0.62555	0.34105	0.2133	0.3912	0.1464
3.	1_{17}	1147	53.10	3.0596	1.7251	-0.53885	-0.30475	0.1642	0.2901	0.09285
4.	1_{18}	734	44.68	2.8658	1.6501	-0.73245	-0.37975	0.2782	0.5365	0.14420
5.	1_{20}	31509.8	259.00	4.4983	2.4133	0.90005	0.38345	0.3451	0.8098	0.14710
6.	1_{23}	23200.5	119.14	4.3655	2.0759	0.76725	0.04605	0.03534	0.5885	0.00212
7.	1_{26}	18668	119.14	4.2709	2.0759	0.67265	0.04605	0.03098	0.4525	0.00212
8.	4_1	9216	138.05	3.9646	2.1399	0.36635	0.11005	0.04030	0.1342	0.01210
9.	4_3	8831	119.14	3.9460	2.0759	0.34775	0.04605	0.01602	0.1209	0.00212
10.	4_5	203.7	105.67	2.3090	2.0237	-1.28925	-0.00615	0.00793	1.6630	0.00004
11.	4_4	4798.7	284.99	3.6810	2.4548	0.08275	0.42495	0.03517	0.0068	0.2273
12.	4_{12}	772	12.82	2.8878	1.1079	-0.7105	-0.92195	0.6551	0.5049	0.8500
		$\bar{Y}$= 3.59825;	$\bar{X}$=2.02985;			-0.0001	0	1.71544	5.7402	1.6730

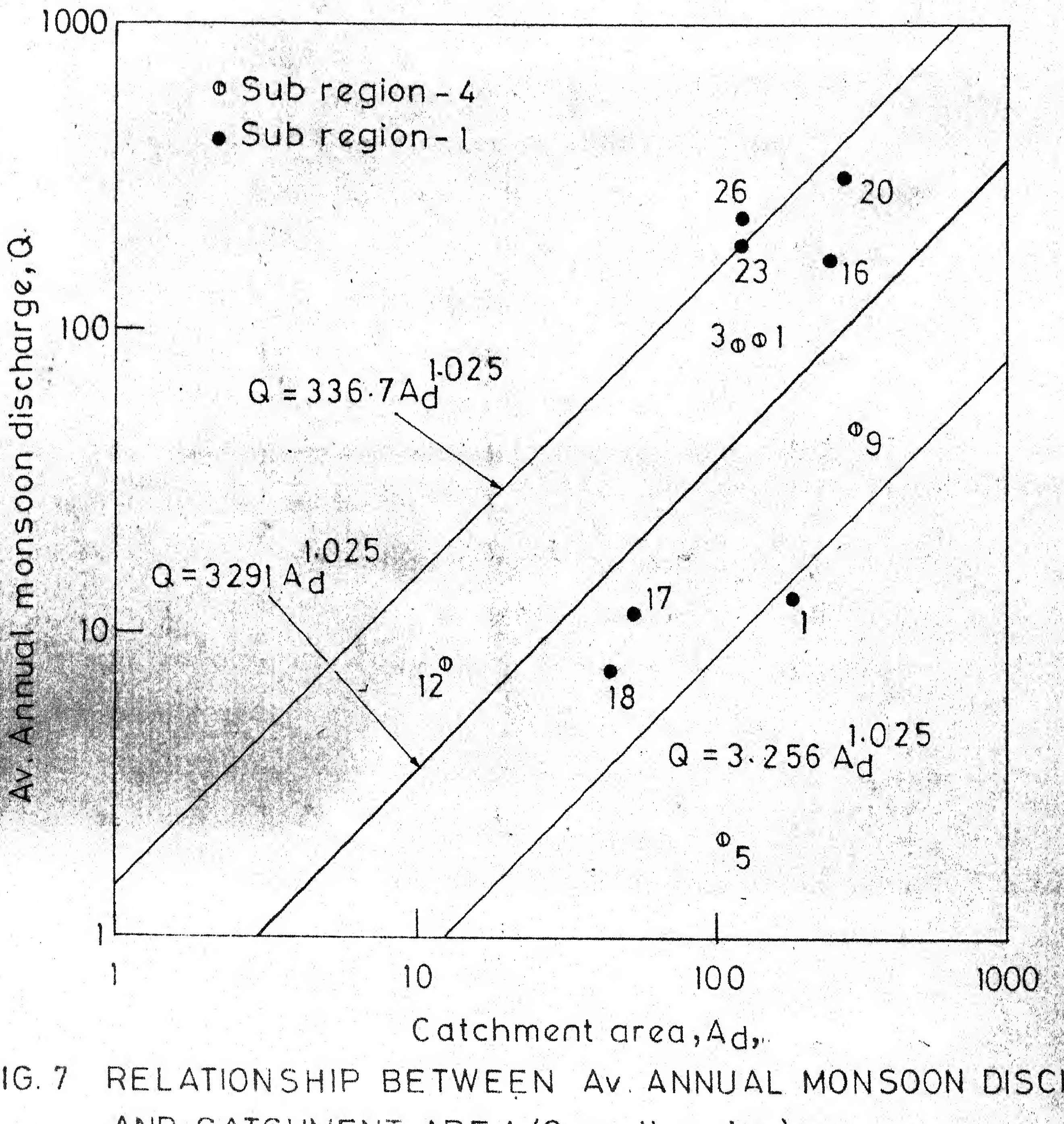


FIG. 7 RELATIONSHIP BETWEEN Av. ANNUAL MONSOON DISCHAR AND CATCHMENT AREA.(Overall region)

4.2 RELATIONSHIP BETWEEN THE CATCHMENT AREA AND THE AVERAGE ANNUAL SEASONAL DISCHARGE.

4.2.1 **General:** The average annual seasonal discharge data corresponding to the catchment area are ploted on the double log- graph papers (Fig. 7). The discharge data are ploted on the ordinate and the catchment area on the abscissa. Before doing analysis tabular charts similar to Table- 1, with slight changes i.e columns3 and 4 indicate average annual discharge and catchment area respectively, whereas, columns 5 and 6 represent logarithmic values of discharge and catchment area respectively, have been prepared for overall region containing sub-regions 1 and 4, and for the subregions 1 and 4 respectively. The above are given in Tables-6,7 and 8 respectively.

Since catchment area and stream length show a direct relationship between themselves, only catchment area is taken as a geomorphologic parameter to obtain relationships with hydrologic parameters.

4.2.2 **Analysis for over all Region:** From Table-6, the following results can be obtained $\bar{X} = 2.02485$; $\bar{Y}=3.59825$; $\sum \Delta X \Delta Y = 1.71544$;

$$\sum(\Delta Y)^2 = 5.7402; \sum(\Delta X)^2 = 1.6730.$$

Hence from eqs. 9 and 10, $A = 1.5173$; $B=1.025$.

Whether the coefficient A is significantly different from $\alpha = 0$, is tested by using eq. 16, with the help of eqs. 11 and 12. From eq.16, $t_A = 1.452$, but $t_{90\%;10d.f.} = 1.3772$. Hence $t_A > t_{90\%;10d.f.}$, which shows that A is significantly different from $\alpha = 0$ at 90% confidence level.

Whether the coefficient B is significantly different from $\beta = 0$ is tested by using eqs. 12, 14, 15, 15a. Hence from eq. 15a, $t_B = 3.39$, but $t_{90\%;10d.f.} = 1.3772$. Hence $t_B > t_{90\%;10d.f.}$, which shows that B is significantly different from $\beta = 0$ at 90% confidence level.

Further, from eq. 11, the value of correlation coefficient, $r = 0.5400$. But $r_{90\%;10d.f.} = 0.576$; therefore, the value of r is not significant at 90% confidence level.

Again from eq. 14, the standard error of estimate, $Se = 0.6163$.

Therefore regression equation for overall region is given by

$$\text{Log } Q = 1.5173 + 1.025 \text{ Log } A_d. \text{ Or } Q = 32.91\, A_d^{1.025} \quad \ldots\ldots 38$$

From eq. 22, the 90% confidence bands can be estimated as follows:

$$\text{Prob } (3.256\, A_d^{1.025} < Q < 336.7\, A_d^{1.025}) = 90\% \quad \ldots\ldots\ldots\ldots 39$$

All the above results are shown in Fig. 7.

TABLE - 7. REGRESS-ION ANALYSIS BETWEEN AVERAGE ANNUAL MONSOON RUNOFF AND CATCHMENT AREA

(Subregion 1.)

Serial No.	CODE LETTER	MEAN ANNUAL DISCHARGE Q.	AREA A_d	LOGARITHM OF Q	LOGARITHM OF A_d	ΔY	ΔX	$\Delta X \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	1_1	1278	176.12	3.1066	2.2458	-0.6634	0.16623	-0.1103	0.4399	0.02762
2.	1_{16}	16744	234.91	4.2238	2.3709	0. 4538	0.29133	0.1322	0.2060	0.08484
3.	1_{17}	1147	53.10	3.0596	1.7251	-0.7104	-0.35447	0.2519	0.5047	0.1582
4.	1_{18}	734	44.68	2.8658	1.6501	-0.9042	-0.42947	0.3885	0.8177	0.1845
5.	1_{19}	31509.8	259.00	4.4983	2.4133	0.7283	0.33373	0.2430	0.5304	0.1114
6.	1_{20}	23200.5	119.14	4.3655	2.0759	-0.0955	-0.00387	-0.0022	0.3546	0.00001
7.	1_{21}	18668	119.14	4.2709	2.0759	0.5069	-0.00367	-0.0018	0.2509	0.00001
		$\bar{Y}$= 3.7700; $\bar{X}$ = 2.07957				0.0005	0.00001	0.9013	3.3918	0.56658

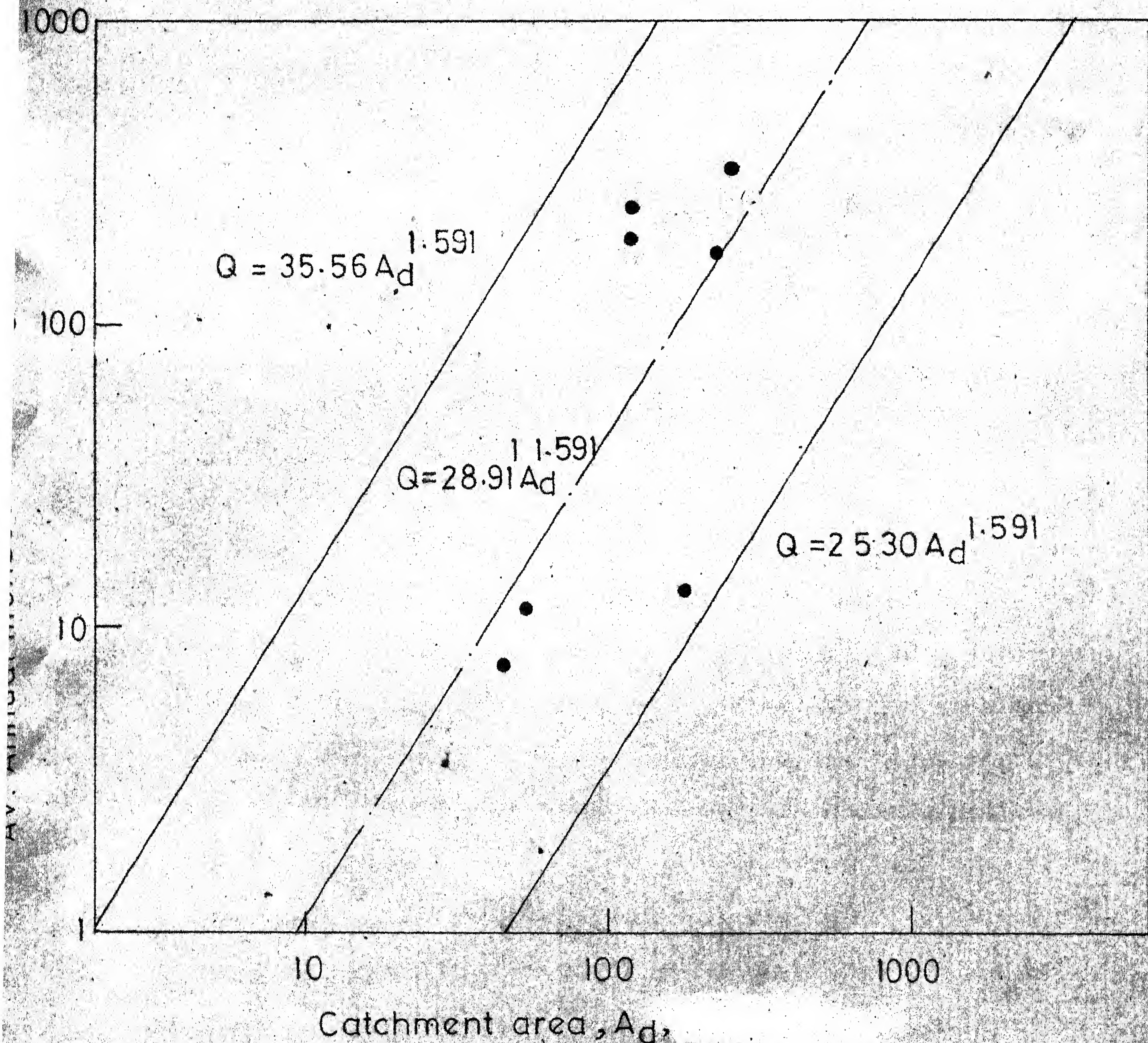


FIG. 8 . REGRESSION RELATIONSHIP BETWEEN Av. ANNUAL MONSOON DISCHARGE AND CATCHMENT AREA . (Subregion=1)

4.2.3 Analysis for Subregions:

4.2.3.1 Subregion 1: The data and the calculations for this subregion are shown in Table - 7. From Table -7, the following results are obtained

$\bar{X} = 2.07957$; $\bar{Y} = 3.7700$; $\sum \Delta X \Delta Y = 0.9013$; $\sum(\Delta Y)^2 = 3.3918$; $\sum(\Delta X)^2 = 0.56658$.

Hence from eqs. 9 and 10, $A_1 = 0.461$ and $B_1 = 1.591$.

Whether the coefficient A_1 is significantly different from $\alpha = 1.517$, is tested by using eq. 16, with the help of eqs. 11 and 12. From eq. 16, $t_{A_1} = 0.6531$. But $t_{90\%;\ 5d.f.} = 1.4759$. Hence $t_{A_1} < t_{90\%;5d.f.}$ which shows that A_1 is not significantly different from $\alpha = 1.5173$ at at 90% level.

Whether the coefficient B_1 is significantly different from $\beta = 1.025$, is tested by using eqs. 12,14, 15 and 15a. From eq. 15a, $t_{B_1} = 6.406$. But $t_{90\%;\ 5d.f.} = 1.4759$. Hence $t_{B1} => t_{90\%;\ 5d.f.}$, which shows that B_1 is significantly different from = 1.025 at 90% confidence level. Further, from eq. 11, the value of correlation coefficient, $r = 0.6795$. But $r_{90\%;\ 5d.f.} = 0.754$. Hence, the value of r is not significant at 90% confidence level.

Again from eq. 14, the standard error of estimate, $Se = 0.6648$. Therefore regression equation for the subregion 1 is given by

$$\text{Log } Q = 0.467 + 1.591 \text{ Log } A_d, \text{ or } Q = 2.891\, A_d^{1.591} \quad \ldots\ldots\ldots 40$$

From eq. 22, the 90% confidence bands are given as

$$\text{Prob } (\ .2350\, A_d^{1.591} < Q < 35.56\, A_d^{1.591}) \ldots\ldots\ldots\ldots\ldots 41$$

All the above results are shown in Fig.7.

TABLE -8. REGRESSION ANALYSIS BETWEEN AVERAGE ANNUAL MONSOON RUNOFF AND CATCHMENT AREA

(Subregion 4)

Serial No.	CODE LETTER	MEAN ANNUAL DISCHARGE Q	AREA A_d	LOGARITHM OF Q	LOGARITHM OF A_d	ΔY	ΔX	$\Delta X \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	4_1	9216	138.05	3.9646	2.1399	0.60692	0.17946	0.1089	0.3684	0.03222
2.	4_3	8831	119.14	3.9460	2.0759	0.58832	0.11546	0.06795	0.3461	0.01335
3.	4_5	203.7	105.67	2.3090	2.0237	-1.04868	0.06326	-0.06633	1.1000	0.00400
4.	4_9	4798.7	284.99	3.6810	2.4548	0.32332	0.49436	0.1599	0.1045	0.24440
5.	4_{12}	772	12.82	2.8878	1.1079	-0.46988	-0.85254	0.4005	0.2208	0.7268
	$\bar{Y}$= 3.35768; $\bar{X}$ = 1.9604;					0.0000	0.0000	0.67092	2.1398	1.0268

4.2.3.2 Subregion 4: The data and calculation for subregion 4 are shown in Table - 8. From Table - 8. the following result can be obtained.

$\bar{X} = 1.9604$; $\bar{Y} = 3.35768$; $\sum \Delta X \, \Delta Y = 0.67092$; $\sum (\Delta Y)^2 = 2.1398$; $\sum (\Delta X)^2 = 1.0268$.

Hence, from eqs. 9 and 10, $A_4 = 2.0767$; $B_4 = 0.6539$

Whether the coefficient A_4 is significantly different from $A = 1.5173$ is tested by using eq.16 with the help of eqs. 11 and 12. From eq. 16, $t_{A4} = 0.3718$. But $t_{90\%;3d.f.} = 1.6377$.

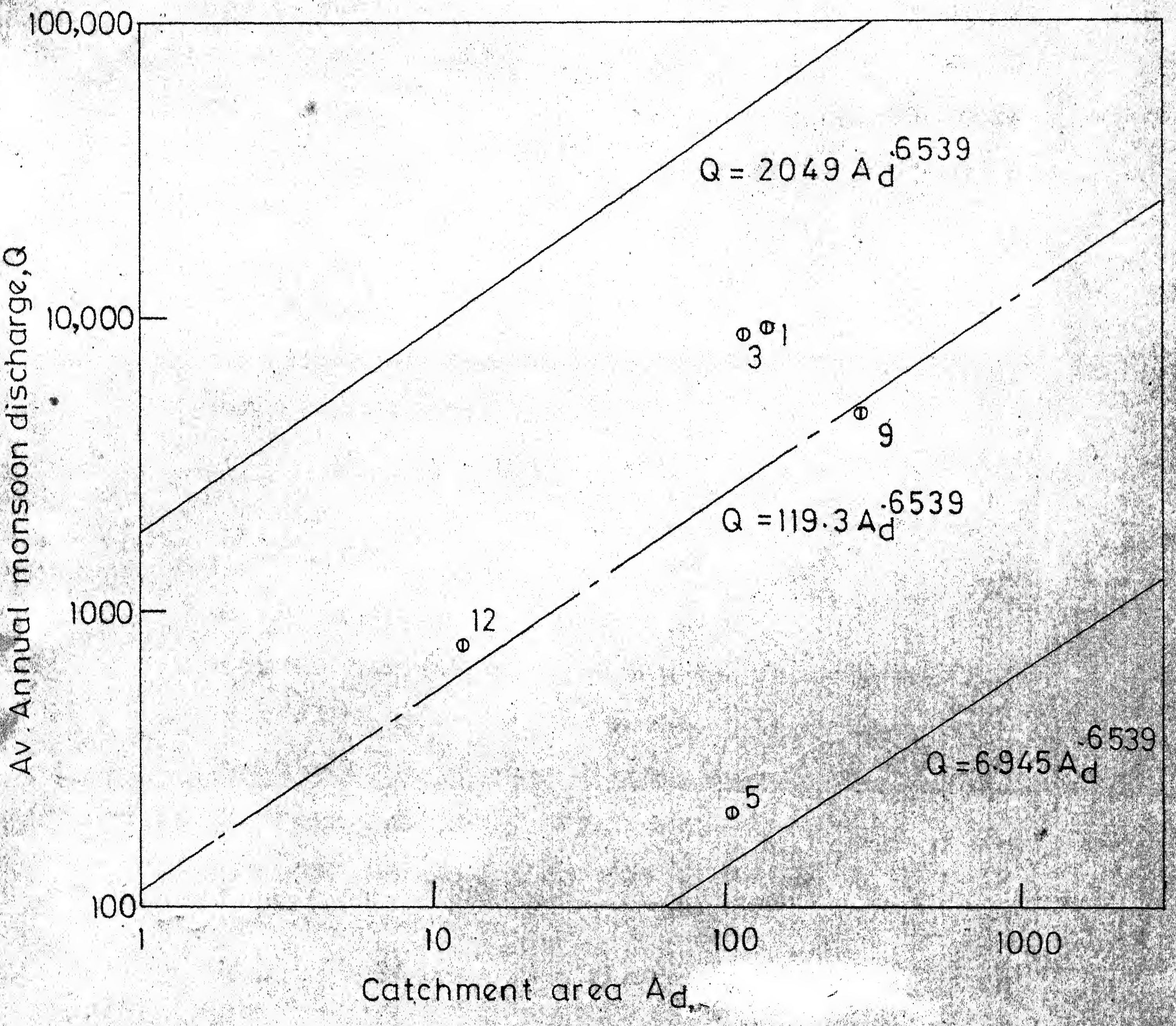


FIG. 9 REGRESSION RELATIONSHIP BETWEEN Av. ANNUAL MONSOON DISCHARGE AND CATCHMENT AREA (Subregion-4)

Hence, $t_{A_4} < t_{90\%;3d.f.}$; which shows that A_4 is not significantly different from $\alpha = 1.5173$ at 90% level.

Whether the coefficient, B_4 is significantly different from $\beta = 1.025$, is tested by using eqs. 12,14, 15 and 15a. From eq. 15a, $t_{B_4} = 0.50$. Hence, $t_{B_4} < t_{90\%;3d.f.}$; which shows that B_4 is not significantly different from $\beta = 1.025$ at 90% level.

Further, from eq. 11, the value of correlation coefficient $r = 0.4528$.

But, $r_{90\%;3d.f.} = 0.878$. Hence the value of r is not significant at 90% level.

Using eq. 14, the standard error of estimate, Se = 0.7530. Therefore regression equation for the subregion 4 is given by,

$$\text{Log } Q = 2.0767 + 0.6539 \text{ Log} A_d \text{ or, } Q = 119.3\ A_d^{0.6539} \quad \ldots 42$$

From, eq. 22 the 90% confidence bands can be estimated as follows

$$\text{Prob}(6.945\ A_d^{.6539} < Q < 2049\ A_d^{.6539}) = 90\% \quad \ldots\ldots\ldots\ldots 43.$$

All the above results are also shown in Fig. 9.

4.2.4 Discussion of results: The results from subsection 4.2.3 indicates that the relationship for subregion 4 is not significantly different from that for the overall region, while that for the only other subregion, i.e. subregion 1 is significantly different . Hence the relationship for subregion 4 also are derived from its own data. The results are given below:

Subregion 1 ; $Q = 2.891\ A_d^{1.591}$, $\text{Prob}\ (.2350\ A_d^{1.591} < Q < 35.56 A_d^{1.59})$ $= 90\%$

Subregion 4; $Q = 119.3\ A_d^{1.6539}$, $\text{Prob}\ (6.945\ A_d^{.6539} < Q < 2049\ A_d^{.6539})$ $= 90\%$

TABLE - 9. REGRESSION ANALYSIS BETWEEN AVERAGE ANNUAL PEAK FLOOD AND CATCHMENT AREA

(Overall region)

Serial No.	CODE LETTER	MEAN PEAK DISCHARGE Qm.	AREA A_d	LOGARITHM OF Qm.	LOGARITHM OF A_d	ΔY	ΔX	$\Delta X \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	1_1	845.83	176.12	2.9773	2.2458	-0.41394	0.21595	-0.08941	0.1713	0.04662
2.	1_{16}	10336	234.91	4.0141	2.3709	0.62286	0.34105	0.2174	0.3880	0.14640
3.	1_{17}	779.83	53.10	2.8919	1.7251	-0.49934	-0.30475	0.1522	0.2494	0.09285
4.	1_{18}	466.6	44.68	2.6690	1.6501	-0.72224	-0.37975	0.2743	0.5193	0.14420
5.	1_{20}	18942	259.00	4.2774	2.4133	0.88616	0.38345	0.3398	0.7852	0.14710
6.	1_{23}	13541	119.14	4.1316	2.0759	0.74036	0.04605	0.03410	0.5480	0.000212
7.	1_{26}	12610	119.14	4.1007	2.0759	0.70946	0.04605	0.03268	0.5032	0.002120
8.	4_1	4078	138.05	3.6105	2.1399	0.21926	0.11005	0.02414	0.4808	0.012100
9.	4_3	4382	119.14	3.6416	2.0759	0.25036	0.04605	0.01153	0.06257	0.002120
10.	4_5	165.33	105.67	2.2183	2.0237	-1.17294	-0.00615	0.00721	1.3760	0.000040
11.	4_9	3319.8	284.99	3.5210	2.4548	0.12976	0.42495	0.05514	1.01684	0.227300
12.	4_{12}	437.83	12.82	2.6413	1.1079	-.74994	-0.92195	0.6915	0.5626	0.850000
		$\bar{Y}$= 3.39124; $\bar{X}$ = 2.02985;				0.00008	-0.00002	1.7390	5.2303	1.6730

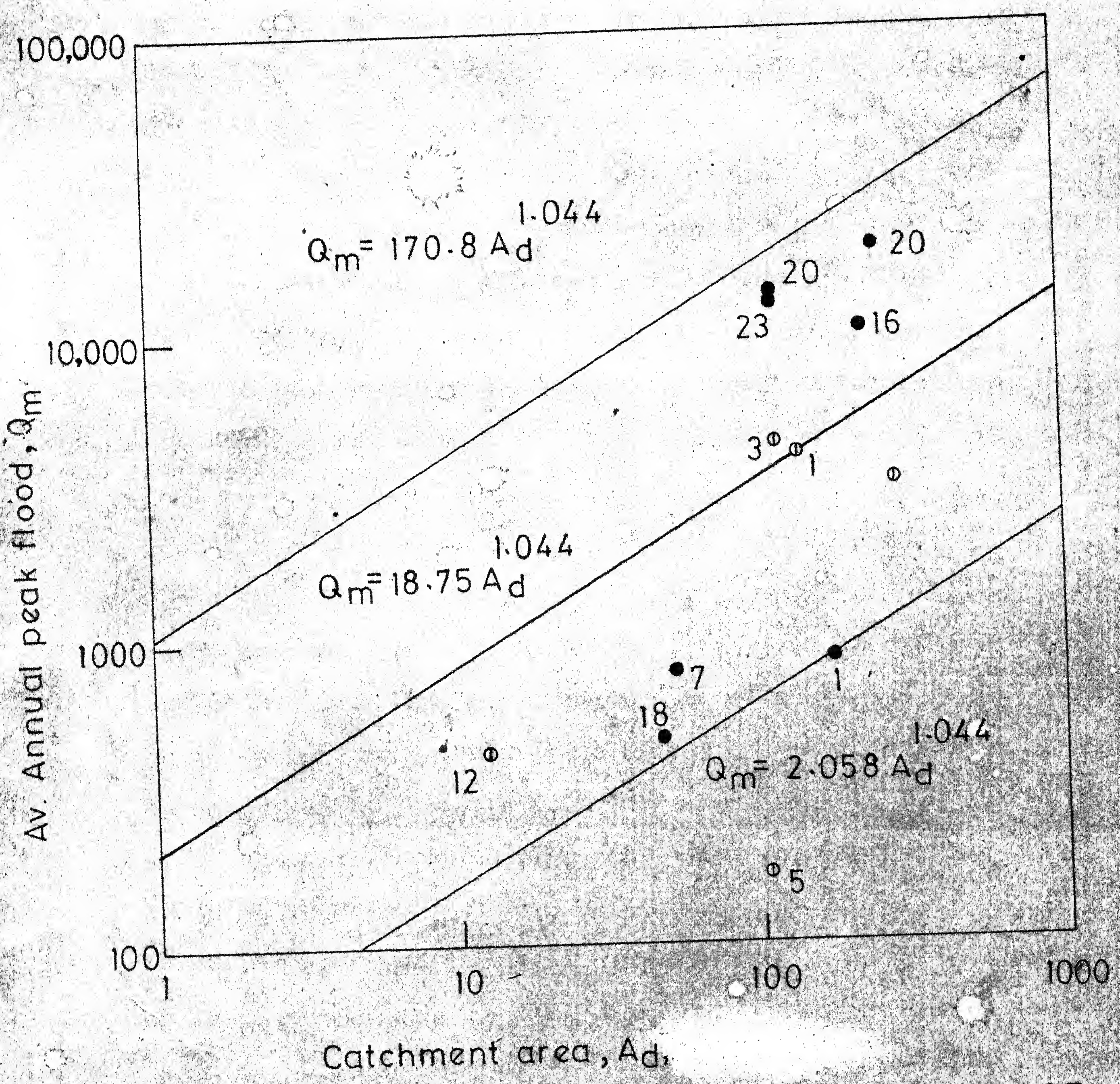


FIG. 10 REGRESSION RELATIONSHIP BETWEEN AVARAGE ANNUAL PEAK FLOOD AND CATCHMENT AREA.

4.3 RELATIONSHIP BETWEEN PEAK DISCHARGE AND CATCHMENT AREA.

4.3.1 General: In this section, the average annual Peak discharge data corresponding to the catchment area are plotted on log-log graph sheets. The average annual Peak discharge are ploted along ordinate while, the catchment area are plotted along abscissa. Tabular charts, similar to Tables-6,7 and 8, with slight modifications i.e. column 3 should indicate average annual peak discharge data and column 5 should indicate logarithm of average annual peak discharge data, have been made for overall region and for the subregions 1 and 4 respectively.

4.3.2 Analysis for Overall Region: The data and calculations for the overall region are shown in Table-9. From Table-9. , the following results can be obtained

$\bar{X} = 2.02985$; $\bar{Y} = 3.39124$; $\sum \Delta X \Delta Y = 1.7390$; $(\Delta Y)^2 = 5.2803$;

$(\Delta X)^2 = 1.6730$.

Hence from eqs. 9 and 10, A= 1.273; B= 1.044.

Whether the coefficient A is significantly different from $\alpha = 0$, is tested by using eq. 16 with the help of eqs. 11 and 12. From eq.16, $t_A = 13.56$, but $t_{90\%;\ 10d.f.} = 1.3722$. Hence $t_A > t_{90\%;\ 10d.f.}$ which shows that A is significantly different from $\alpha = 0$ at 90% confidence level.

Whether the coefficent B is significantly different from $\beta = 0$, is tested by using eqs. 12, 14, 15 and 15a. From eq. 15a. $t_B = 1.517$. Hence $t_B > t_{90\%;\ 10d.f.}$ which shows that B is significantly different from $\beta = 0$ at 90% confidence level.

Further, from eq. 11, the value of correlation coefficient $r = 0.5878$. But $r_{90\%;\ 10 d.f.} = 0.576$. Hence the value of r is significant at 90% confidence level.

Using eq 14, the standard error of estimate $Se = 0.5851$. Therefore regression equation for the overall region is given by

$$\text{Log } Qm = 1.273 + 1.044 \text{ Log } A_d; \text{ or } Qm = 18.75\ A_d^{1.044} \quad \ldots\ldots\ldots\ldots \quad 44$$

From eq. 22, the 90% confidence bands can be estimated as follows:

$$\text{Prob } (\ 2.058\ A_d^{1.044} < Qm < 170.8\ A_d^{1.044}) = 90\% \quad \ldots\ldots\ldots\ldots\ldots \quad 45$$

All the above results are shown in Fig. 10.

TABLE - 10. REGRESSION ANALYSIS BETWEEN AVERAGE ANNUAL PEAK FLOOD AND CATCHMENT AREA

(Subregion 1)

Serial No.	CODE LETTER	MEAN PEAK DISCHARGE Qm	AREA A_d	LOGARITHM OF Qm	LOGARITHM OF A_d	ΔY	ΔX	$\Delta X \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	1_1	845.83	176.12	2.9773	2.2458	-0.6030	0.16623	-0.1002	0.3636	0.02762
2.	1_{16}	10336	234.91	4.0141	2.3709	0.4338	0.29133	0.1264	0.1882	0.08484
3.	1_{17}	779.83	53.12	2.8919	1.7251	-0.6884	-0.35447	0.2441	0.4741	0.1582
4.	1_{18}	466.60	44.68	2.6690	1.6501	-0.9113	-0.42947	0.3913	0.8303	0.1845
5.	1_{20}	18942	259.00	4.2774	2.4133	0.6971	0.33373	0.2326	0.4860	0.1114
6.	1_{23}	13541	119.14	4.1316	2.0759	0.5513	-0.00367	-0.002023	0.3040	0.00001
7.	1_{26}	12610	119.14	4.1007	2.0759	0.5204	-0.00367	-0.00191	0.2708	0.00001
	$\bar{Y} = 3.5803$; $\bar{X} = 2.07957$					-0.0001	0.00001	0.8903	2.9170	0.56658

4.3.3 Analysis for Subregions.

4.3.3.1 Subregion 1. The data and calculations for subregion 1 are given in Table 10. From Table 10, the following results are obtained :

$\bar{X} = 2.07957$; $\bar{Y} = 3.5803$; $\sum \Delta X \Delta Y = 0.8903$; $\sum(\Delta Y)^2 = 2.9170$; $\sum(\Delta X)^2 = 0.56658$.

Hence from eqs. 9 and 10, $A_1 = 0.3133$; $B_1 = 1.570$.

Whether the coeffcient A_1 is significantly different from $\alpha = 1.273$ is, tested by using eq. 16 with the help of eqs. 11 and 12. From eq. 16, $t_{A_1} = 0.127$; but $t_{90\%;\ 5d.f.} = 1.4759$. Hence $t_{A_1} < t_{90\%\ 5d.f.}$, which shows that A_1 is not significantly different from $\alpha = 1.273$ at 90% confidence level.

Whether the coefficient B_1 is significantly different from $\beta = 1.044$, is tested by using eqs. 14, 15, 12 and 15a. From eq. 15a., $t_{B_1} = 0.6324$, but $t_{90\%;\ 5d.f.} = 1.4759$. Hence, $t_{B_1} < t_{90\%;\ 5d.f.}$, which shows that B_1 is not significantly different from $\beta = 1.044$ at 90% confidence level.

Further, from eq. 11, the value of correlation coefficient $r = 0.6844$; but $r_{90\%;\ 5d.f.} = 0.754$. Hence the value of r is not significant at 90% confidence level.

Using eq. 14, the standard error of estimate, Se= 0.5569.

The relationship between the average annual peak discharge and the catchment area and, 90% confidence bands have been derived in Sec. 4.3.2 Therefore from equation 44, the regression equation for the subregion 1 is given by

$$Qm = 18.75\ A_d^{1.044} \quad \ldots 44$$

and hence, the corresponding confidence bands at 90% confidence level from eq. 45,

$$\text{Prob}\ (2.058\ A_d^{.044} < Qm < 170.8\ A_d^{1.044}) = 90\% \quad \ldots 45$$

TABLE - 11. REGRESSION ANALYSIS BETWEEN AVERAGE ANNUAL PEAK FLOOD AND CATCHMENT AREA

(Subregion 4)

Serial No.	CODE LETTER	MEAN PEAK DISCHARGE Q_m	AREA A_d	LOGARITHM Q_m.	LOGARITHM A_d	ΔY	ΔX	$\Delta X \Delta Y$	$(\Delta Y)^2$	$(\Delta X)^2$
1.	4_1	4078	138.05	3.6105	2.1399	0.4839	0.17946	0.86860	0.2341	0.03222
2.	4_3	4382	119.14	3.6416	2.0759	0.5150	0.11546	0.5947	0.2653	0.01335
3.	4_5	165.33	105.67	2.2183	2.02237	-0.9083	0.06326	-0.05745	0.8249	0.00400
4.	4_9	3319.8	284.99	3.5210	2.4548	0.3944	0.49436	0.19500	0.1555	0.2444
5.	4_{12}	437 .83	12.82	2.6413	1.1079	-0.4853	-0.85254	0.41370	0.2355	0.7268
		$\bar{Y}$ = 3.1266; $\bar{X}$ = 1.96044;				-0.0003	0.00000	1.47932	1.7153	1.0268

4.3.3.2 Subregion 4 . The data and calculations for subregion 4 are given in **Table -11.** From **Table - 11.** the following results are obtained.

$\bar{X}$= 1.96044; $\bar{Y}$=3.1266; $\sum \Delta X \Delta Y$=1.47932; $\sum (\Delta Y)^2 = 1.7153$; $\sum (\Delta X)^2 = 1.0268$.

Hence, from eqs. 9 and 10, $A_4 = 1.2876$; $B_4 = 0.9378$.

Whether the coefficient A_4 is significantly different from α=1.273, is tested by using eq. 16, with the help of eqs. 11 and 12. From eq. 16, $t_{A_4} = 0.01436$. But $t_{90\%;\ 3d.f.} = 1.6377$.

Hence $t_{A4} < t_{90\%;3d.f.}$, which shows that A_4 is not significantly different from $\alpha = 1.273$ at 90% confidence level.

Whether the coefficient B_4 is significantly different from $\alpha = 1.044$ is, tested by using eqs. 12, 14, 15 and 15a. From eq. 15a., $t_{B_4} = 0.1651$. But $t_{90\%;\ 3d.f.} = 1.6377$. Hence, $t_{B4} < t_{90\%;\ 3d.f.}$, which shows that B_4 is not significantly different from $\beta = 1.044$ at 90% confidence level.

Further, from eq. 11, the value of correlation coefficient, $r = 0.7252$. But $r_{90\%;\ 3d.f.} = 0.878$. Hence, the value of r is not significant at 90% confidencelevel.

Using, eq. 14, standard error of estimate, $Se = 0.5769$.

The relationship between the average annual peak discharge and the catchment area, and, 90% confidence bands have been derived in Sec.4.3.2. Therefore, from eq. 44, the regression equation for the subregion 4 is given by, $Qm = 18.75\ A_d^{1.044}$, and hence, the corresponding 90% confidence bands, from eq. 45,

$$\text{Prob}\ (2.058\ A_d^{1.044} < Qm < 170.8 A_d^{1.044}) = 90\%.$$

4.3.4 Discussion of Results: The results in subsections 4.3.3 indicate that the relationships for the subregions 1 and 4 are not statistically different from that for the overall region. Hence the average annual flood peak in the region can be estimated from the equation.

$Qm = 18.75\ A_d^{1.044}$; and the 90% confidence interval is given by the equation

$$\text{Prob}\ (2.058\ A_d^{1.044} < Qm < 170.8\ A_d^{1.044}) = 90\%.$$

It may be noted that the confidence bands are rather wide. In case data for more basins in the region are available, it may be possible to reduce the width ofthe confidence band and have more reliable predictions for basins without data.

CHAPTER - 5.

SUMMARY, CONCLUSIONS AND SUGGESTIONS FOR THE FUTURE STUDY.

5.1 SUMMARY: Hydrologic data are generally available only for limited number of basins and for limited time. As the soil and landform are moulded by the environment and particularly by the hydrologic cycle it is logical to expect close relationships, within geomorphologic characteristics of the basin and between the hydrologic characteristics and geomorphologic characteristics of the basin. For a region in North India data for stream length, and the catchment area, , are available for 63 basins and are distibuted over four subregions. It is found that the general equation of the exponential form can be fitted between the stream length and the basin area, namely, $A_d = C L^n$, where C and n are empirical constants and were estimated from data. But the coefficients are different for each subregion. The 90% confidence levels were also derived for the above relationships.

The hydrologic characterestics considered in this study are

i. the average annual monsoon runoff, Q, for the basin, and

ii. the average annual peak flood, Qm, for the basin. It was found that exponential relationships can be derived between the above hydrologic characterestics and the basin area, namely, $Q = R A_d^S$, and $Qm = p A_d^q$, where R, S, p and q are empirical coefficients estimated from data. From the limited data available it was found that R and S varied from subregion to subregion, while, p and q were constants. The 90% confidence levels for the above relationships also have been defined. On the basis of available data the above relationships c

be used for predicting the average annual monsoon runoff and the average annual peak flood for the basin along with their respective confidense intervals.

The results are valid only for the regions for which they have been derived. However similar relationships can be derived for the other regions as well, and used to estimate the streamflow and floods in basins with inadquate data.

5.2 CONCLUSIONS:

As the soil and landform are moulded by environment and particularly hydrologic cycle, the hydrologic characteristics of the basin and geomorphologic characteristics of the basin should be closely related. Hence when hydrologic data are scarce it may be possible to establish such correlation between the hydrologic data and geomorphologic data and use it for estimating hydrologic characteristics of basin with limited or no data. It has been seen from analyses that relationships between the i. geomorphologic parameters and ii. geomorphologic parameter and hydrologic parameters are of the exponential form.

5.3 SUGGESTION FOR THE FUTURE STUDY:

The scope of the present study is limited by time and availability of data. On the basis of the present study there is scope for further study including the followings

i. using a 1 inch = 1 mile toposheet, geomorphological parameters can be evaluated and correlated among themselves and with appropiate hydrologic characteristics.

ii. Other hydrologic characteristics, including sediment, groundwater, etc. can also be considered, and

iii. The results of study may be useful for identifying geohydrological regions.

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